NASA's Lunar Communications & Navigation (C&N) Architecture

Jim Schier, SE&I Manager
NASA Space Communications & Navigation (SCaN) Office

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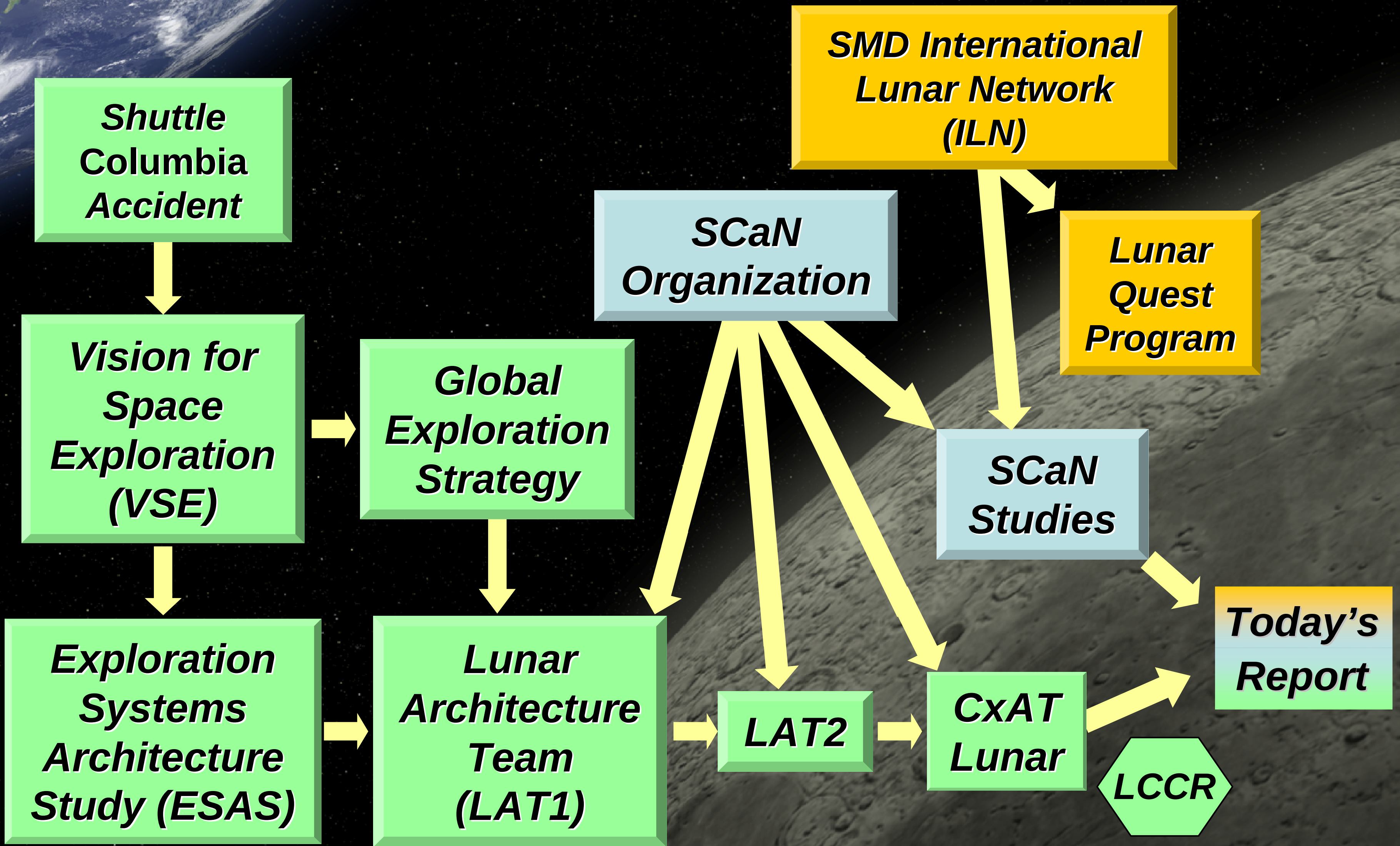
Agenda

- Context for Change
- Lunar Network in the context of Exploration Systems
  - Communications
  - Navigation
  - Networking
- Lunar Network in the context of Science's International Lunar Network
- Lunar Network in the context of NASA's Integrated Network Architecture
  - Communications, Navigation & Networking Services
  - Integrated Service Portal
  - Commercial & International Partnering
- Conclusion
- SE Challenges

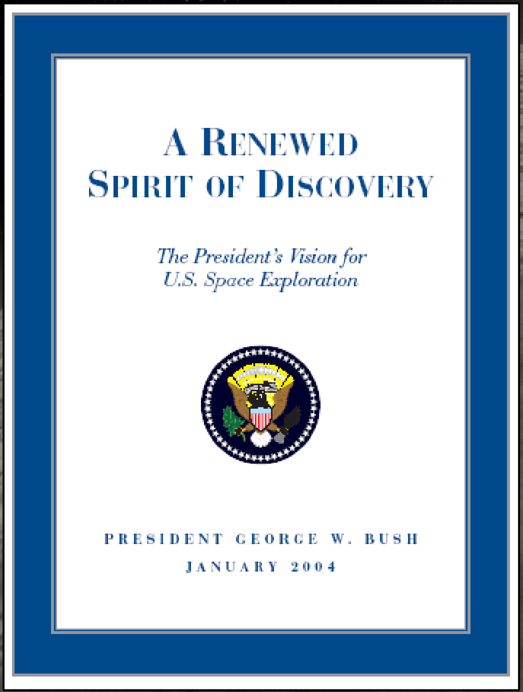
Path to Today



- Program: Lunar Capability Concept Review
- Project: Ares V / Altair Mission Concept Review

A Bold Vision for Space Exploration, Authorized by Congress

- **Complete the International Space Station**
- **Safely fly the Space Shuttle until 2010**
- **Develop and fly the Crew Exploration Vehicle no later than 2014**
- **Return to the Moon no later than 2020**
- **Extend human presence across the solar system and beyond**
- **Implement a sustained and affordable human and robotic program**
- **Develop supporting innovative technologies, knowledge, and infrastructures**
- **Promote international and commercial participation in exploration**



NASA Authorization Act of 2005

The Administrator shall establish a program to ***develop a sustained human presence on the Moon***, including a robust precursor program to promote exploration, science, commerce and U.S. preeminence in space, and ***as a stepping stone to future exploration of Mars*** and other destinations.

Context for Organization Change to SCaN

- **Networks reorganized under Space Operations Mission Directorate into the Space Communications and Navigation Office (SCaN) charged with these priorities:**
  - **Transition towards a single, unified mission support architecture**
  - **Manage ground & space-based facilities of existing networks (Space Network/Tracking & Data Relay Satellite System, Near Earth Network, Deep Space Network) and future Lunar and Mars Networks**
  - **Oversee evolution of terrestrial network architecture (NASA Integrated Services Network) managed by CIO as part of Agency infrastructure**
  - **Automate capabilities and develop technology to reduce costs**
  - **Advocate and develop communications standards**
  - **Advocate and defend spectrum use**
  - **Strengthen inter-Agency cooperation and partnership**
  - **Build international cooperation and interoperability**

THE PROPOSED INTERNATIONAL LUNAR NETWORK (ILN)

- NASA's Science Mission Directorate is initiating an effort to coordinate future lunar landed missions into an International Lunar Network (ILN).
- The ILN is designed to emplace 6-8 stations on the lunar surface, forming a second-generation geophysical network.
- Individual stations could be fixed or mobile.
- Each ILN station would fly a core set of instrument types (e.g., seismic, laser retro-reflector, heat flow) requiring broad geographical distribution on the Moon.
- Each ILN station could also include additional passive, active, ISRU, or engineering experiments, as desired by each sponsoring space agency.

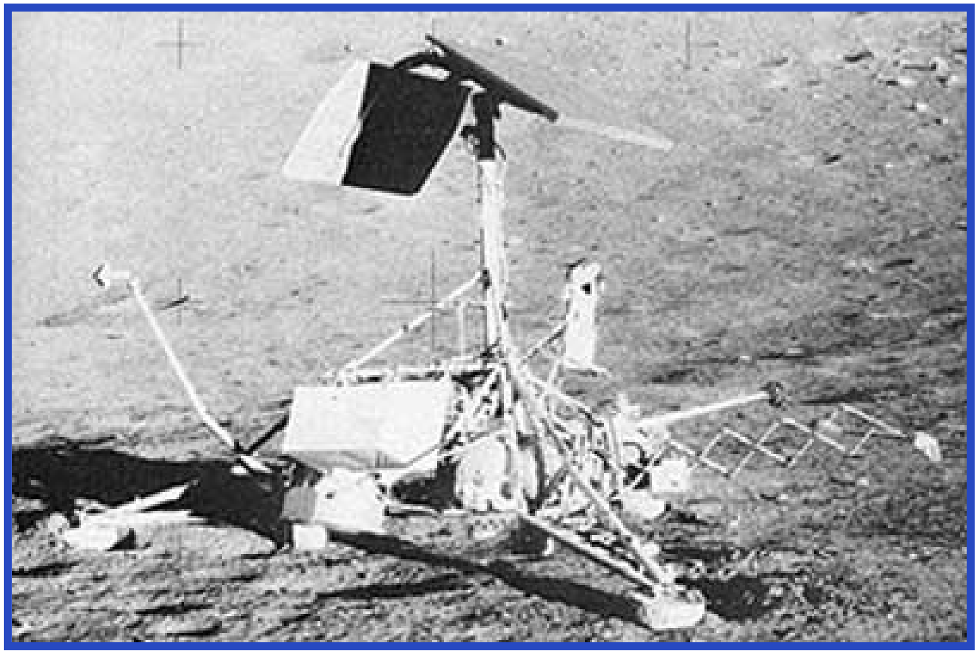
Source: International Lunar Network briefing by Dr. Alan Stern, 12 March 2008

US ILN CONTRIBUTIONS

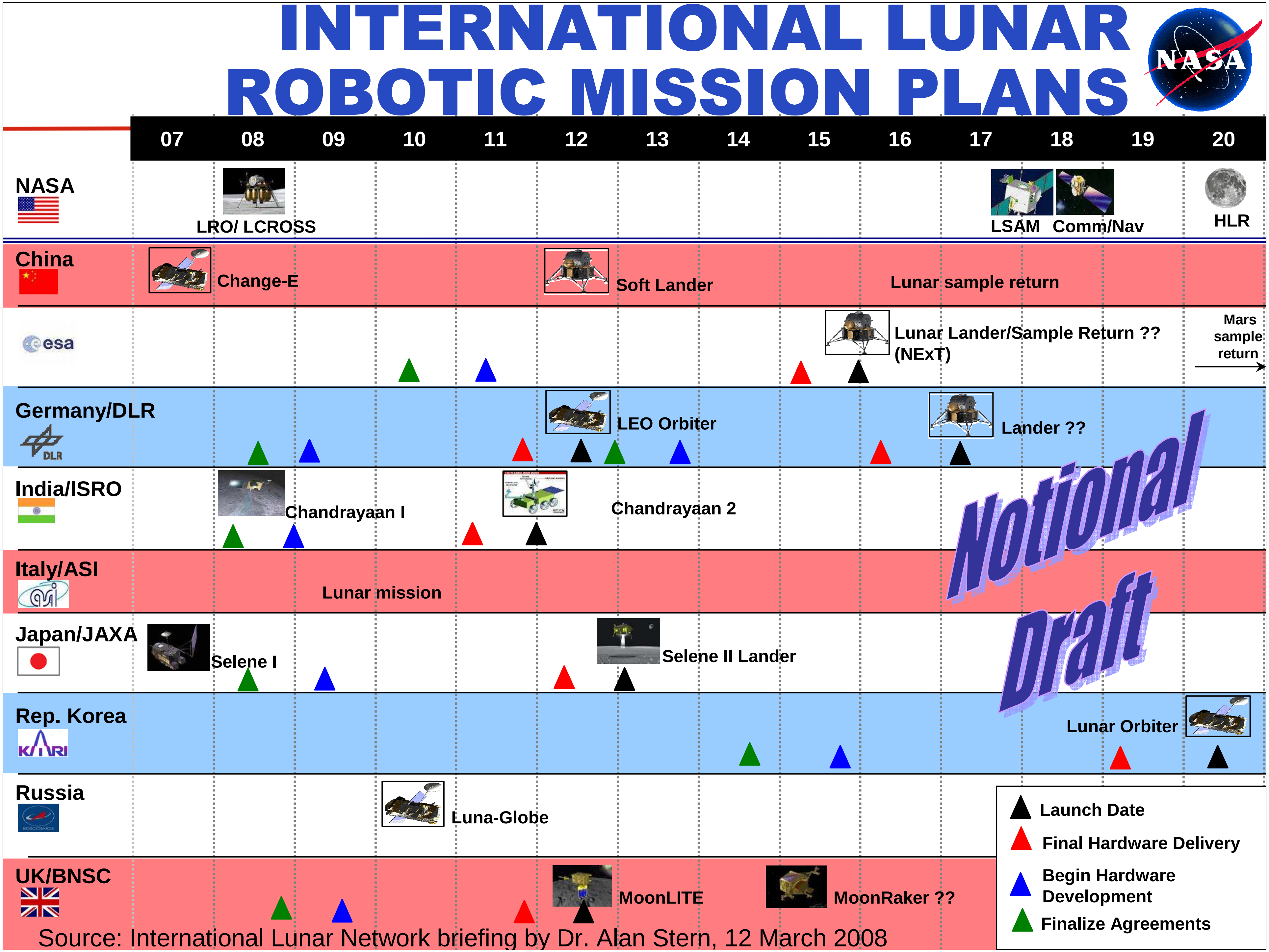
- The US is committing now to two ILN nodes, launched to the lunar poles, in 2013/2014.

- The US is studying the option for a lunar comm relay orbiter enabling lunar far-side access for ILN nodes.

- The US is planning a second pair of ILN nodes in 2016/2017.



Source: International Lunar Network briefing by Dr. Alan Stern, 12 March 2008


INTERNATIONAL LUNAR ROBOTIC MISSION PLANS
NASA
07
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18
19
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NASA
LRO/ LCROSS
LSAM
Comm/Nav
HLR
China
Change-E
Soft Lander
Lunar sample return
esa
Lunar Lander/Sample Return ?? (NExT)
Mars sample return
Germany/DLR
DLR
LEO Orbiter
Lander ??
India/ISRO
Chandrayaan I
Chandrayaan 2
Italy/ASI
Lunar mission
Japan/JAXA
Selene I
Selene II Lander
Rep. Korea
KARI
Lunar Orbiter
Russia
Luna-Globe
UK/BNSC
MoonLITE
MoonRaker ??
Notional Draft
Launch Date
Final Hardware Delivery
Begin Hardware Development
Finalize Agreements
Source: International Lunar Network briefing by Dr. Alan Stern, 12 March 2008

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  - Communications
  - Navigation – Position, Navigation, & Timing (PNT)
  - Networking
- Lunar Network in the context of Science's International Lunar Network
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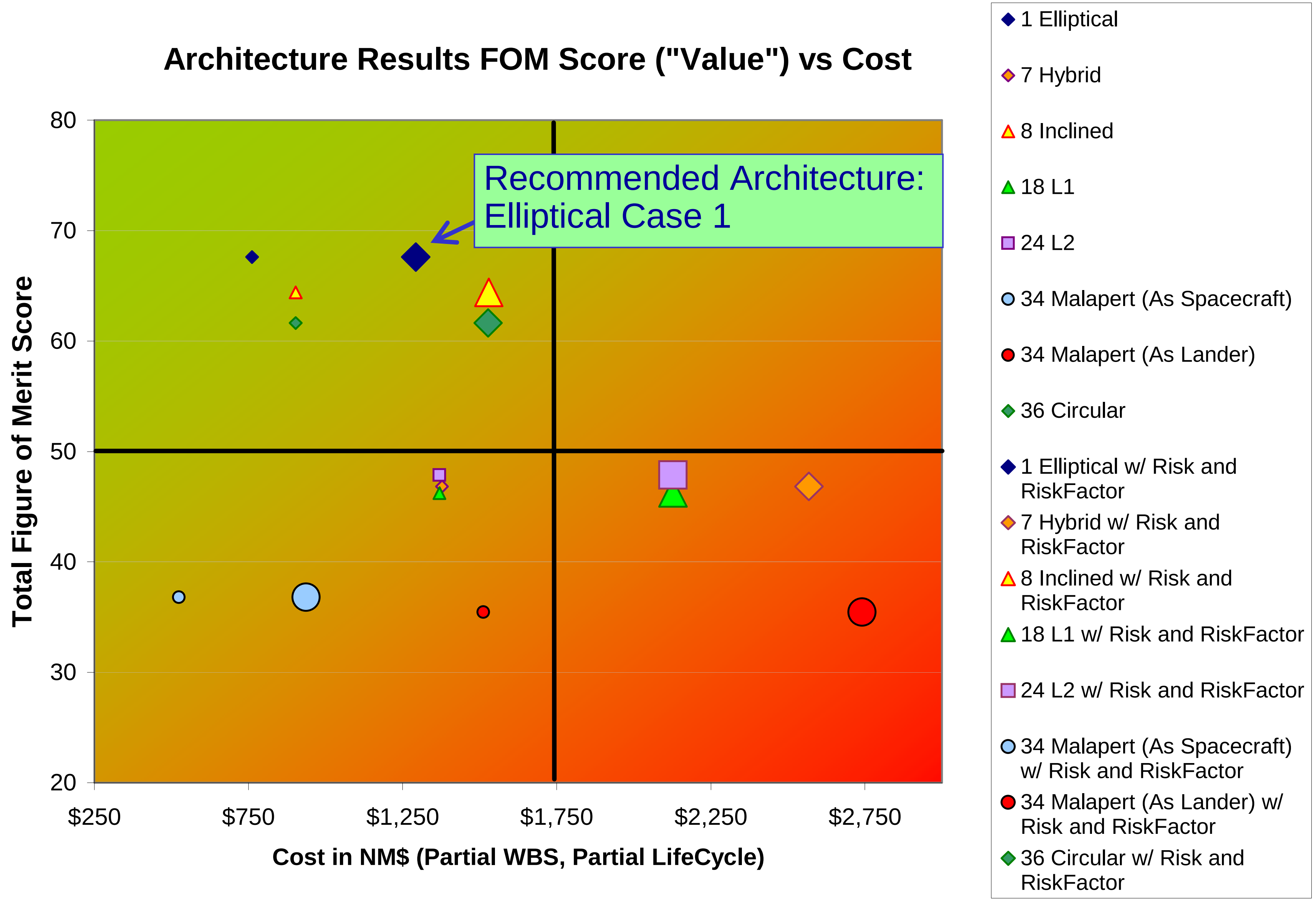
Lunar Relay Orbit Options Evaluated (2004-6)

Lunar Relay Alternatives Studied	
South Pole Study	Elliptical Orbit – 2 Relays in a single orbit plane with semi-major axis of 6540 km and an eccentricity of 0.6
	Hybrid Orbit – 3 Relays in a circular equatorial orbit and 3 in a circular polar orbit with radius of 9200 km
	Inclined Circular Orbit – 3 Relays in a 70° inclined plane at a radius of 6430 km
	L1 Lagrange Halo Orbit – 5 Relays in a large circular halo for continuous SP coverage, near and far-side
	L2 Lagrange Halo Orbit – 5 Relays in a large circular halo for continuous SP coverage, near and far-side
	Polar Circular Orbit Class – 3 Relays in a 5300 km radius orbit
	Landed Communications Tower at Malapert Mountain near the South Pole
Full Coverage	8 Relays: 4 Relays in a circular polar orbit + 4 Relays in a perpendicular polar plane. Orbit radius 9250 km.
	12 Relays: 3 Relays spaced equally in each of four polar circular planes. Orbit radius 9250 km.
	6 Relays: 3 Relays in a circular polar orbit + 3 Relays in a perpendicular polar plane. Orbit radius 9250 km.
	6 Relays: 3 in an inclined circular plane + 3 in a perpendicular plane. Orbit radius 8050 km, inclination 52.2°.
	5 Relays: Five separate planes, each with one relay. Orbit radius 9150 km, inclination 43.7°.
	6 Relays: "Lang-Meyer" configuration of 4 inclined circular planes with one relay in each, + 2 relays in an equatorial circular orbit. Orbit radius 8050 km, inclination 58.9°.
	7 Relays: A hybrid configuration of 4 relays in elliptical orbits, one orbit with a northern apoapsis the other southern, plus 3 relays in an inclined circular plane perpendicular to the elliptical planes. Elliptical plane inclination 56.1°, eccentricity 0.6. Circular orbit radius 11575 km, 33.9° inclination.
Deployment Trades	Small deployable communications package for far-side critical event coverage only. Deploy from the carrier vehicle during after trans-lunar injection vs. deploy after lunar orbit insertion.
	Pre-deployment of complete or partial constellations using ELVs vs. single relay deployment via piggyback on Constellation vehicles to build assets over time
	"Cover as you go": Provide continuous coverage to humans only vs. to humans and science / robotics left at prior sortie sites. Build up relay assets incrementally as needed.

Source: Space Comm Architecture Working Group (SCAWG) NASA Space Comm & Navigation Architecture Recommendations for 2005-2030, 15 May 2006, Final Report

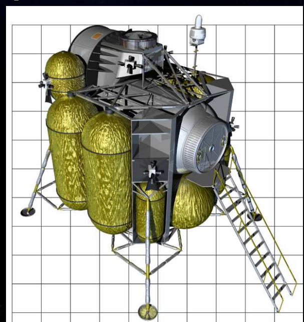
South Pole Study Results: Composite Benefit vs. Cost

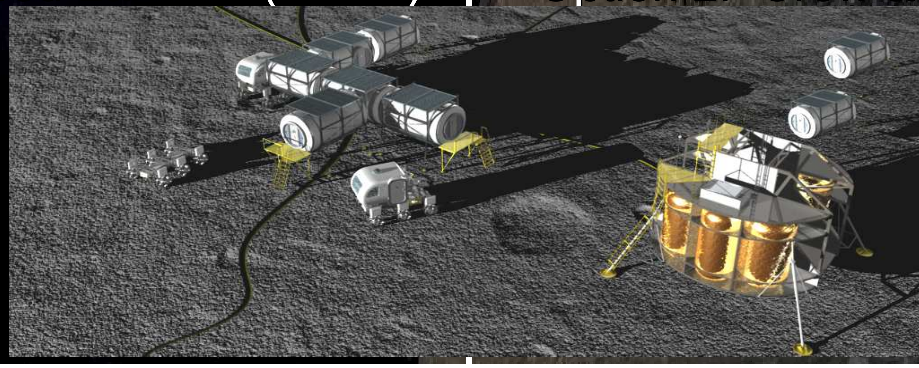


Source: Space Comm Architecture Working Group (SCAWG) NASA Space Comm & Navigation Architecture Recommendations for 2005-2030, 15 May 2006, Final Report

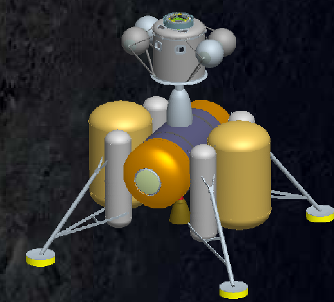
Lunar Architecture Options Evaluated

Option 1: All Crewed Landers (LAT 1)



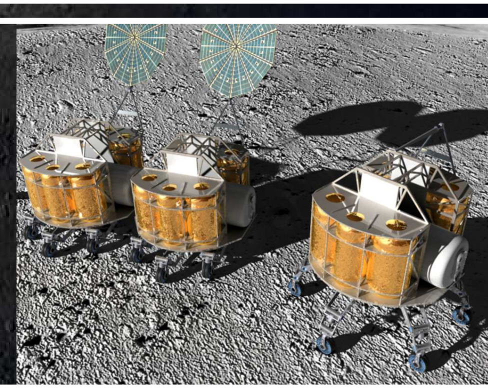


Option 2: Crew & Cargo Landers

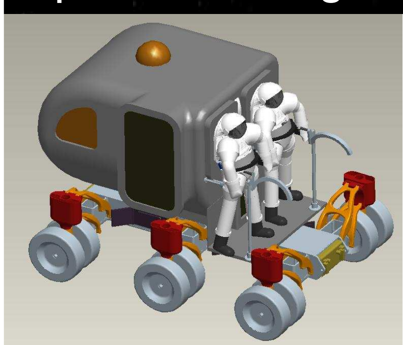


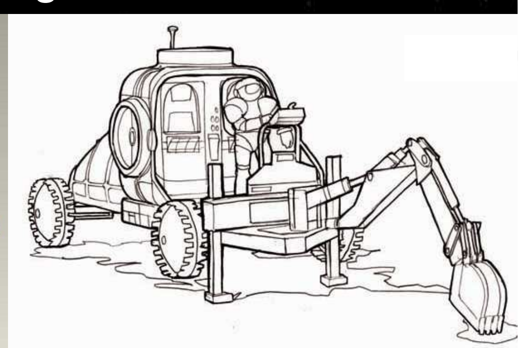
Option 3:
Pre-integrated
Monolithic
Habitat

Option 4:
Mobile
Lander

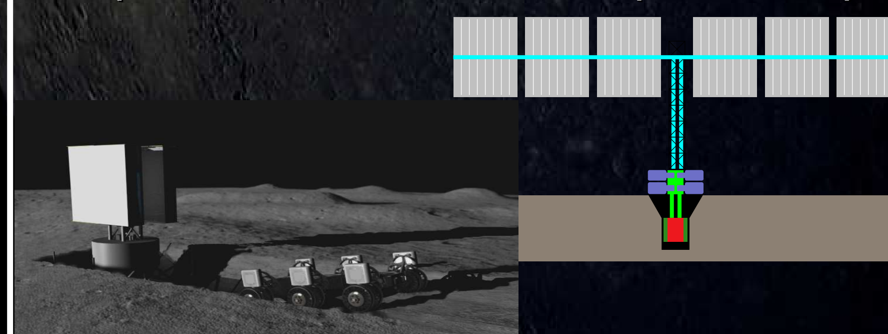


Option 5: Long range, Pressurized Rover





Option 6: Nuclear Power (vice solar)



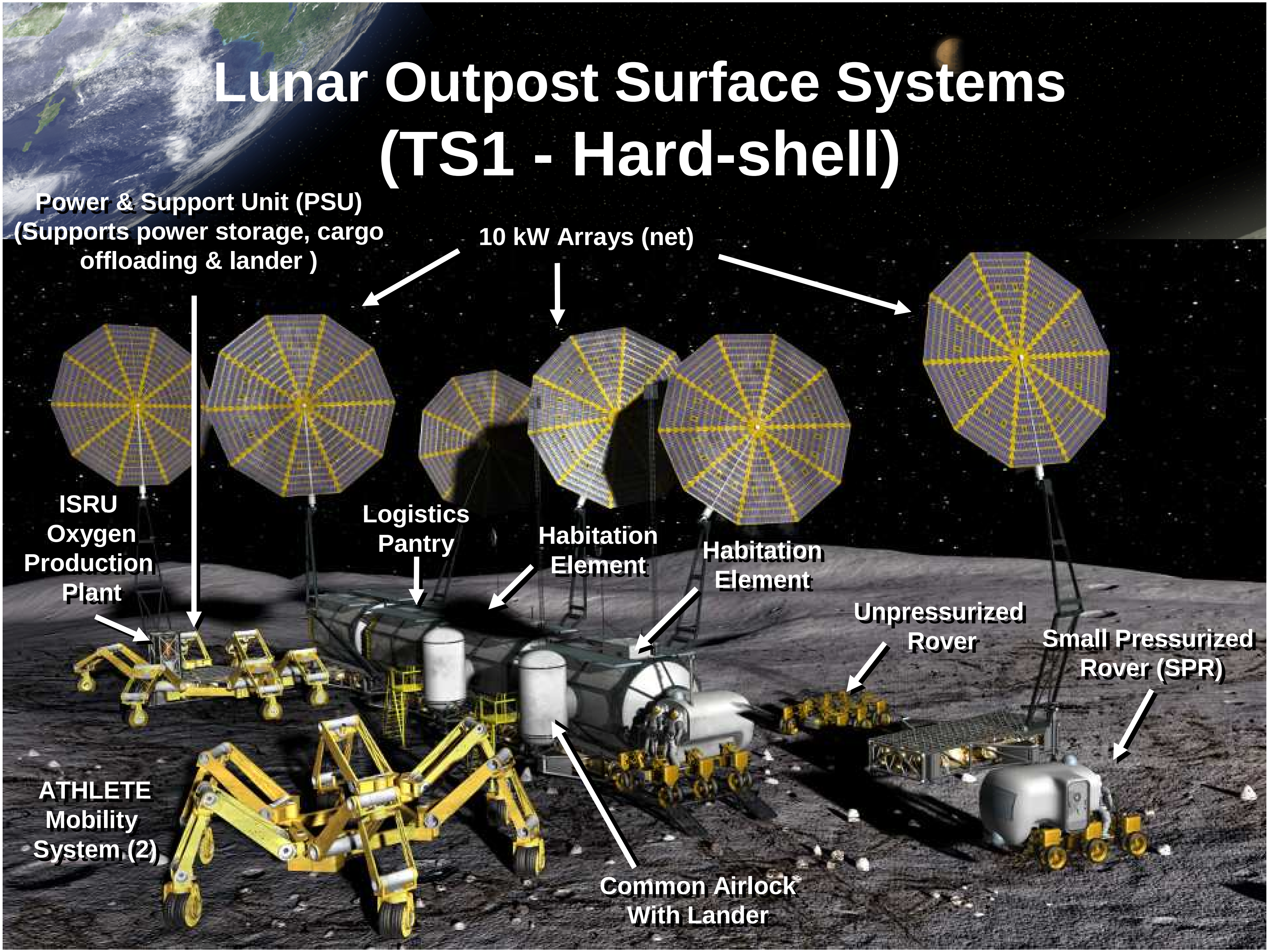
Driving Surface Architecture Characteristics

- **Pervasive Mobility**
  - Science enabler / range extender
  - Ability to adapt outpost elements to more locations on the lunar surface
  - Always something new to explore
- **Mission Flexibility**
  - Minimally functional outpost capability established as early as possible
  - Build Outpost at any rate with steadily increasing capabilities: “go as you pay”
  - Outpost can recover rapidly from loss of elements (modular and reconfigurable)
  - Adjust Outpost buildup to accommodate changing science & mission priorities
- **Global Connectivity**
  - Able to perform global lunar exploration via sorties and long distance roving
  - HD cameras & High bandwidth communications
  - International, commercial & university participation
  - Virtually connecting the above to engage scientists & the general population on both Globes
- **Long Duration**
  - More time for Science
  - Highly reliable systems
  - Minimize logistics needs
  - Outpost can be implemented to emulate Mars surface scenarios
  - Core technologies and operations applicable to Mars exploration

CxAT Surface Architectures Assessed

Three surface architectures were developed in support of LCCR:

- **Rapid Outpost Buildup (TS-1)**
  - Deliver as much outpost capability as soon as transportation system permits
  - Full-up outpost based on the recommendations from LAT-2.
  - Substantial robustness through element duplication
- **Initial Mobility Emphasis (TS-2)**
  - Temper outpost build-up based on affordability with initial emphasis on mobility capabilities
  - Full-up outpost has less volume and limited eclipse operating capability than TS1
  - Robustness achieved through functional reallocation
  - Assumed water scavenging
- **Initial Habitation Emphasis (TS-3)**
  - Temper outpost build-up based on affordability with initial emphasis on core habitation & exploration capabilities
  - Full-up outpost has less volume and limited eclipse operating capability than TS1
  - Robustness achieved through functional reallocation
  - Assumed water scavenging


Lunar Outpost Surface Systems
(TS1 - Hard-shell)
Power & Support Unit (PSU)
(Supports power storage, cargo
offloading & lander)
10 kW Arrays (net)
ISRU
Oxygen
Production
Plant
Logistics
Pantry
Habitation
Element
Habitation
Element
Unpressurized
Rover
Small Pressurized
Rover (SPR)
ATHLETE
Mobility
System (2)
Common Airlock
With Lander

Fundamental Tenets for C&N

- Functionally independent from the architecture of other systems to prevent continuous design changes inherent in tightly coupled systems
- Extensible and open to inserting new services, adding capacity, increasing performance, inserting new technology, and adding new partners
- Interoperable based on the use of international standards enabling full collaboration and coordination of operations, introduction of new technologies and capabilities, a low entry barrier for new participants, and preventing being held hostage by proprietary interfaces or equipment
- Compatible with terrestrial communication infrastructure to reduce risk and cost by providing seamless communications from Earth to the Moon leveraging the enormous investments already made in existing communication infrastructure inside and outside of NASA as well as new investments being made in global telecommunications technologies; and
- Robust in the face of anticipated and unanticipated failures by providing diverse communication paths and providing two independent navigation data types in each mission phase.

16

C&N Element Summary

Overview

C&N services are provided via Relays & surface Lunar Comm Terminals (LCT) for the outpost with periodic Direct To Earth (DTE) capability. Relays cover entire lunar surface for sorties.

Concept of Operations

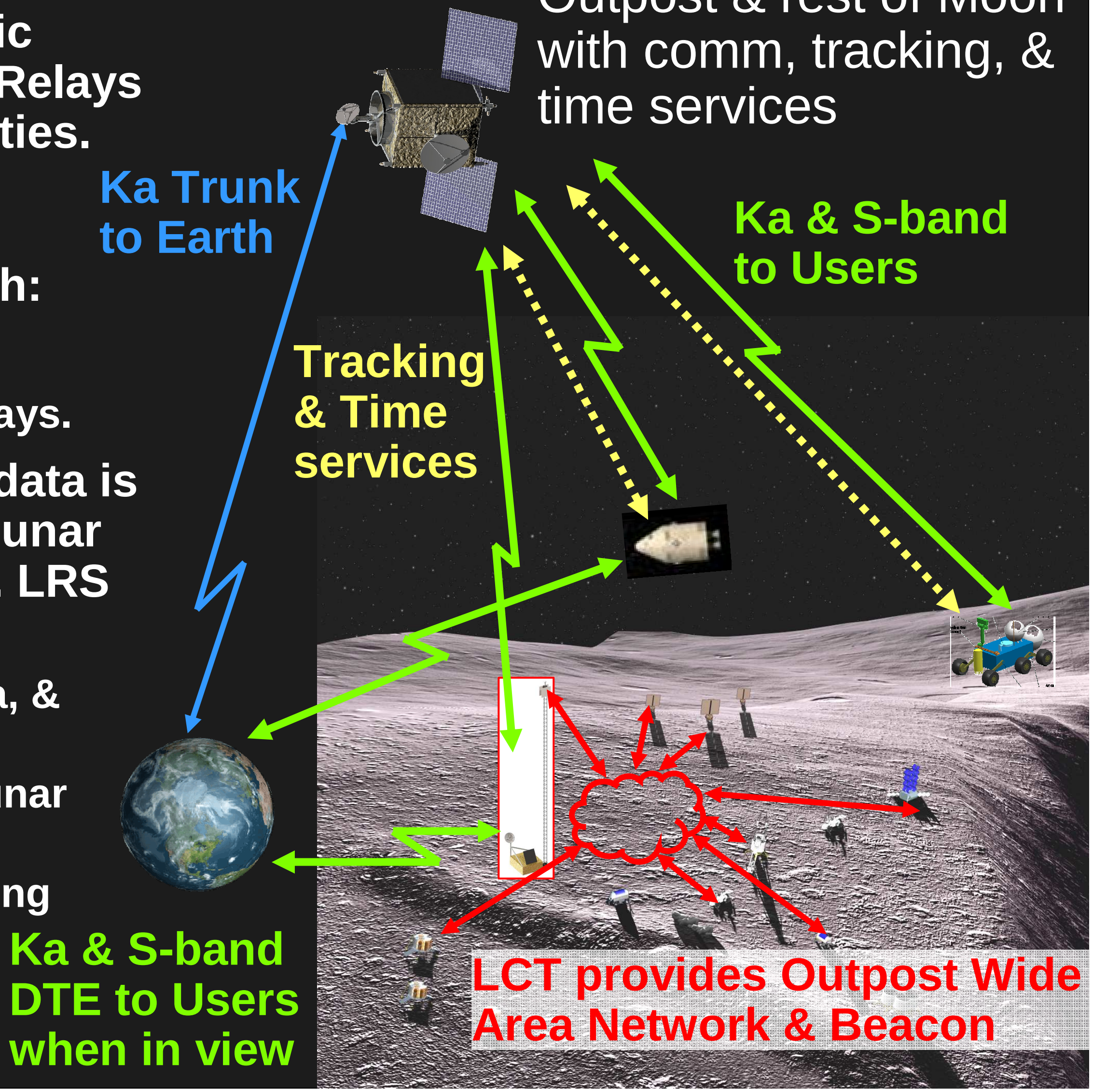
There is redundant comm to Earth:

- **Early missions via DTE and 1 relay**
- **Extended missions via DTE & 2 relays.**

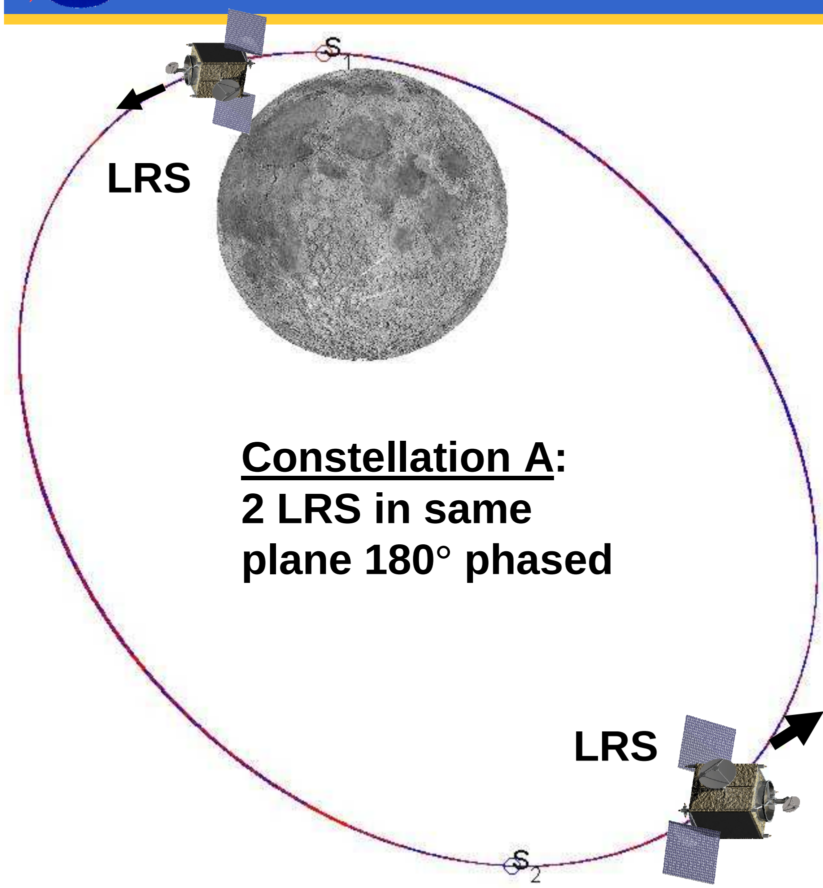
For surface operations, Outpost data is routed through the LCT to other lunar users or to Earth via DTE or LRS. LRS & LCT provide these services:

- **Forward & return voice, video, data, & TT&C**
- **Fully routed data between Earth, lunar orbit, & lunar surface users**
- **1 & 2-way ranging & Doppler tracking**
- **Surface Navigation Beacons**
- **Time dissemination & synchronization**

Lunar Relay Satellite (LRS): Coverage of Outpost & rest of Moon with comm, tracking, & time services

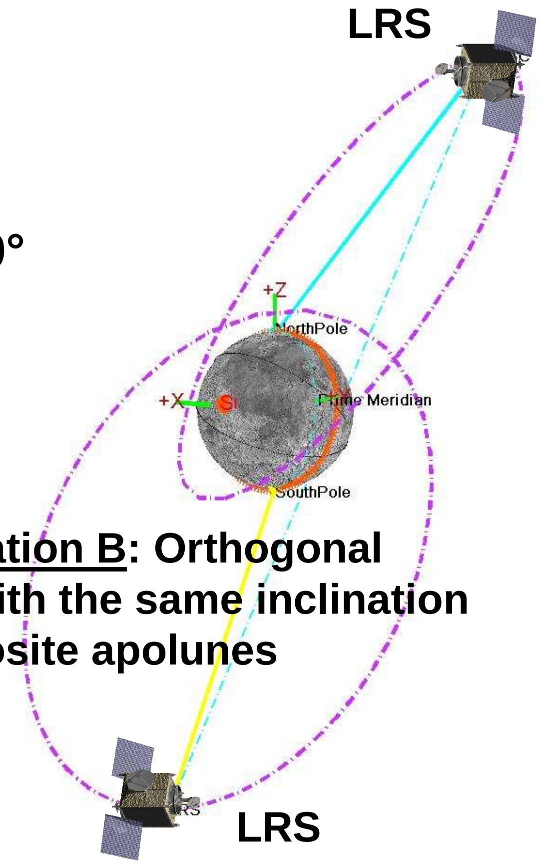


Orbit Options



Constellation A:
2 LRS in same plane 180° phased

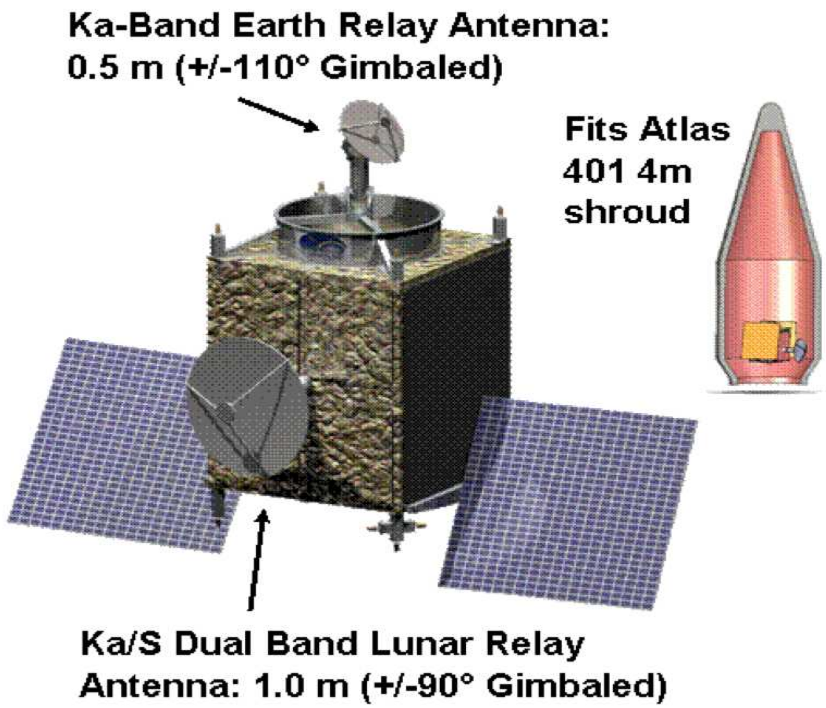
LRS:
- **SMA= 6142.4 km**
- **Eccentricity=0.59999**
- **Inclination=57.7°**
- **Perilune Argument=90°**
- **12-Hour Orbits**



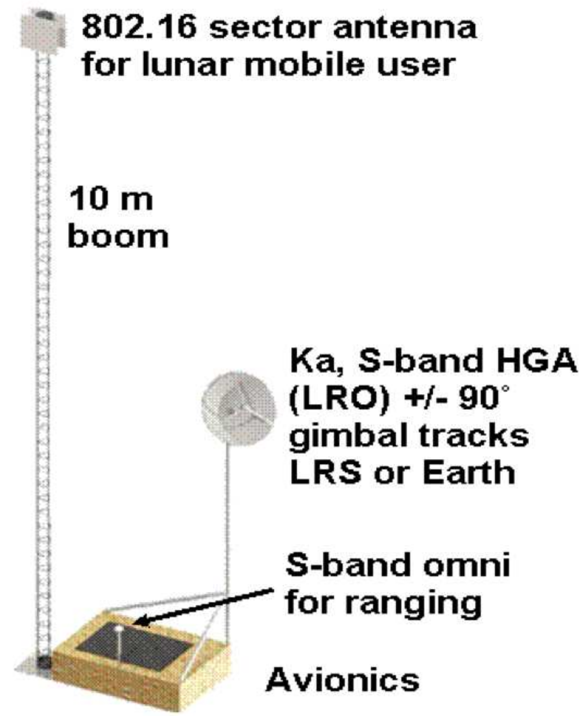
Constellation B: Orthogonal planes with the same inclination and opposite apolunes

- **Using LRS as designed (i.e., no additional NRE or RE), operational options are available to support missions over the entire lunar surface at the same level of performance**
  - **Tradeoff: Two relays in the same orbit provides good coverage of 1 hemisphere with an operational satellite plus on-orbit spare. Two relays in different orbits provides full surface coverage at the expense of no on-orbit spare.**

Lunar Relay Satellite & Lunar Comm Terminal



Lunar Relay Satellite (LRS)



Lunar Communications Terminal (LCT)

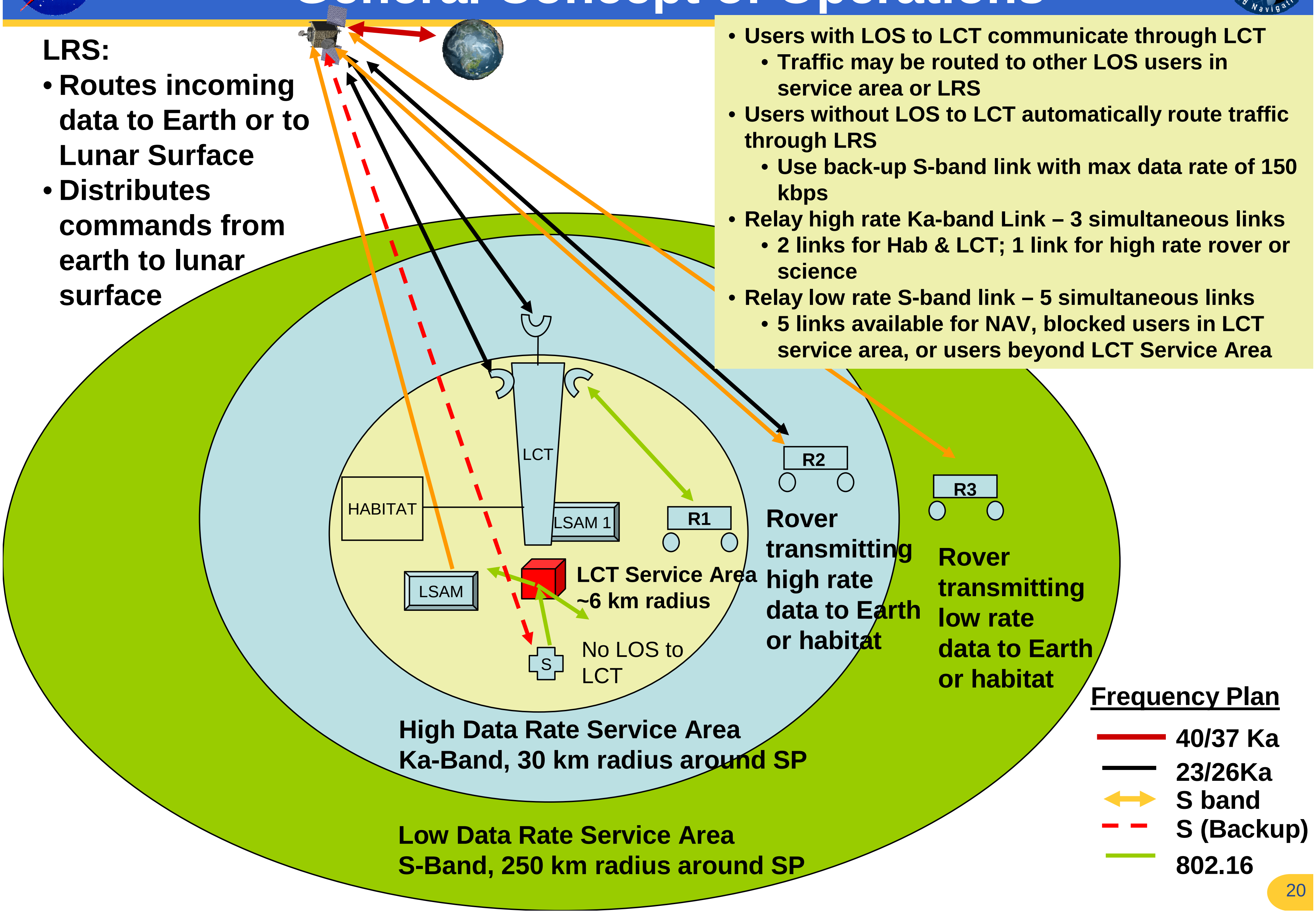
- Lunar comm relay, navigation, network, & timing
  - 7 year life with fuel for 10 years
  - Each LRS single fault tolerant
- Atlas 401 or Delta IV Medium: >60% launch margin
  - Options exists for dual launch or secondary payloads
- Communications and Navigation Payloads
  - 2x100 Mbps high rate links from Surface, 2x25 Mbps low rate from other surface; Fully IP-routed
  - 2-way ranging to up to 5 users simultaneously
  - 24 hr Store & Forward with 300 GB storage

- Lunar comm relay, navigation, network, & timing
  - 80 Mbps 802.16e WLAN for lunar surface, 5.8 km range
  - 200 Mbps Ka to LRS (or Earth)
  - 25 Mbps S-band to LRS (or Earth); 192 kbps safe mode
- Integrated into Altair or Hab or Deployed
- Command & Data Handling
  - 300 GB data recorder, general avionics processor
  - Time generation unit, atomic clock

General Concept of Operations

LRS:
- Routes incoming data to Earth or to Lunar Surface
- Distributes commands from earth to lunar surface

- Users with LOS to LCT communicate through LCT
  - Traffic may be routed to other LOS users in service area or LRS
- Users without LOS to LCT automatically route traffic through LRS
  - Use back-up S-band link with max data rate of 150 kbps
- Relay high rate Ka-band Link – 3 simultaneous links
  - 2 links for Hab & LCT; 1 link for high rate rover or science
- Relay low rate S-band link – 5 simultaneous links
  - 5 links available for NAV, blocked users in LCT service area, or users beyond LCT Service Area

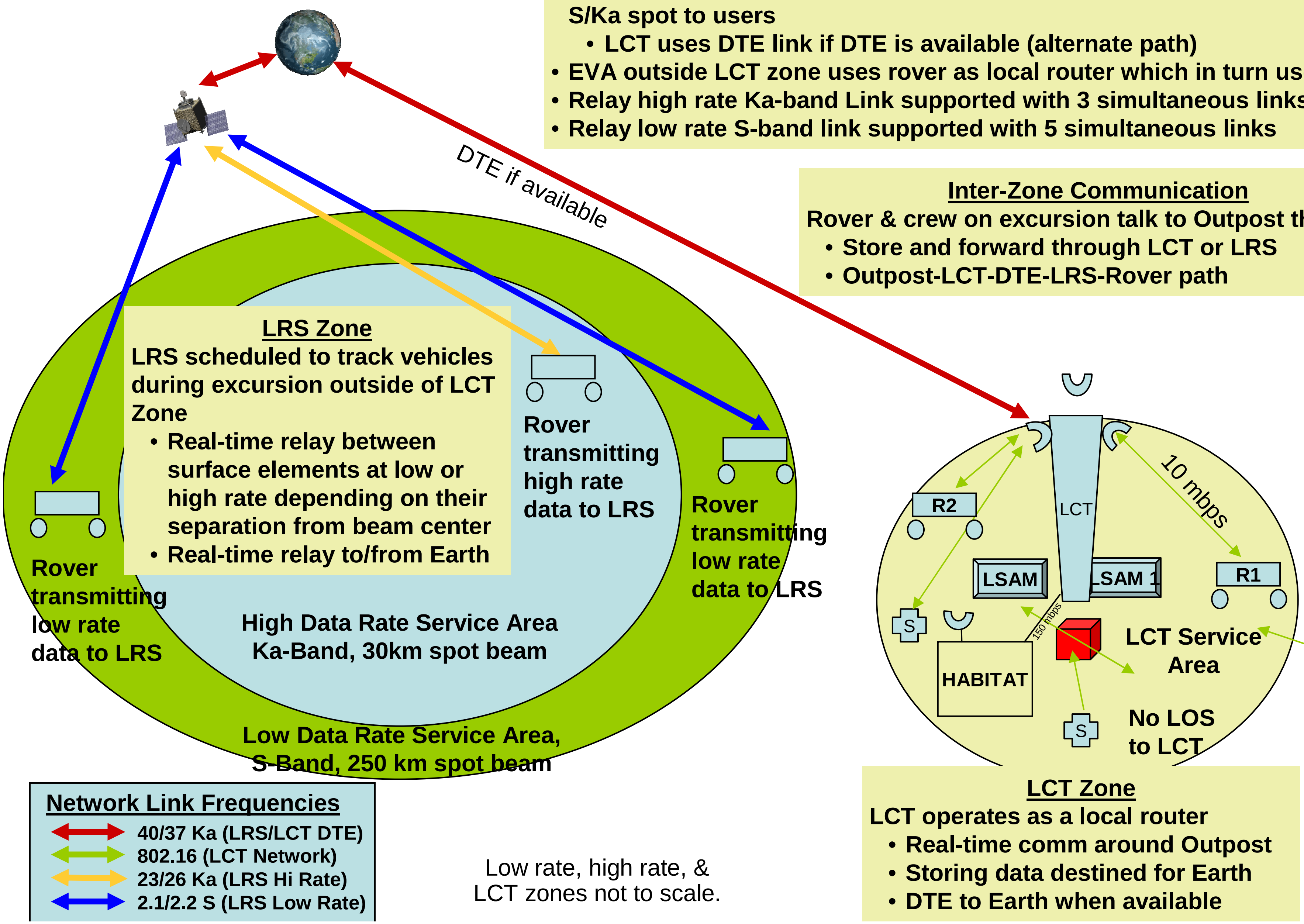


Separated LRS and LCT Service Zones

- Outside LCT zone (no LOS to LCT) primary path is through LRS directing S/Ka spot to users
  - LCT uses DTE link if DTE is available (alternate path)
- EVA outside LCT zone uses rover as local router which in turn uses LRS
- Relay high rate Ka-band Link supported with 3 simultaneous links
- Relay low rate S-band link supported with 5 simultaneous links

Inter-Zone Communication

Rover & crew on excursion talk to Outpost through:
- Store and forward through LCT or LRS
- Outpost-LCT-DTE-LRS-Rover path



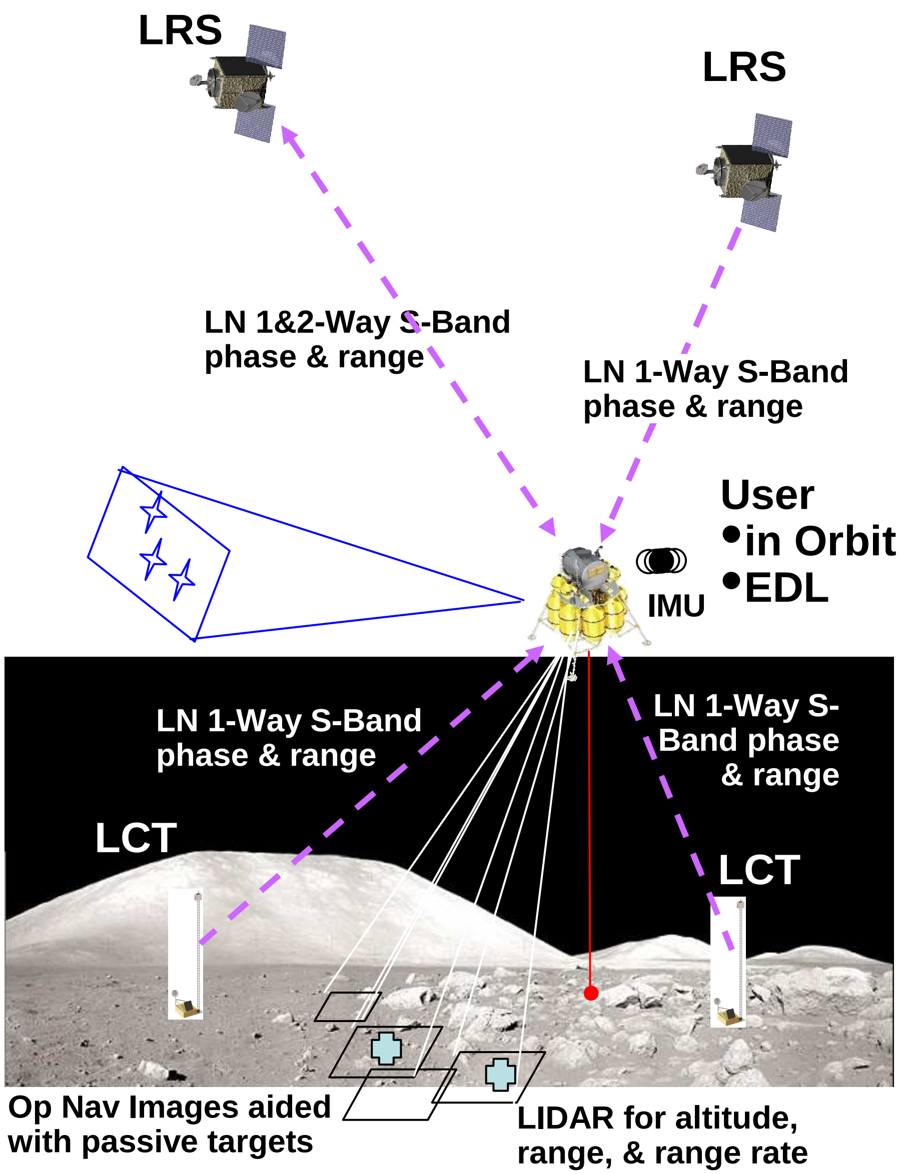
LCT Zone

LCT operates as a local router
- Real-time comm around Outpost
- Storing data destined for Earth
- DTE to Earth when available

Low rate, high rate, & LCT zones not to scale.

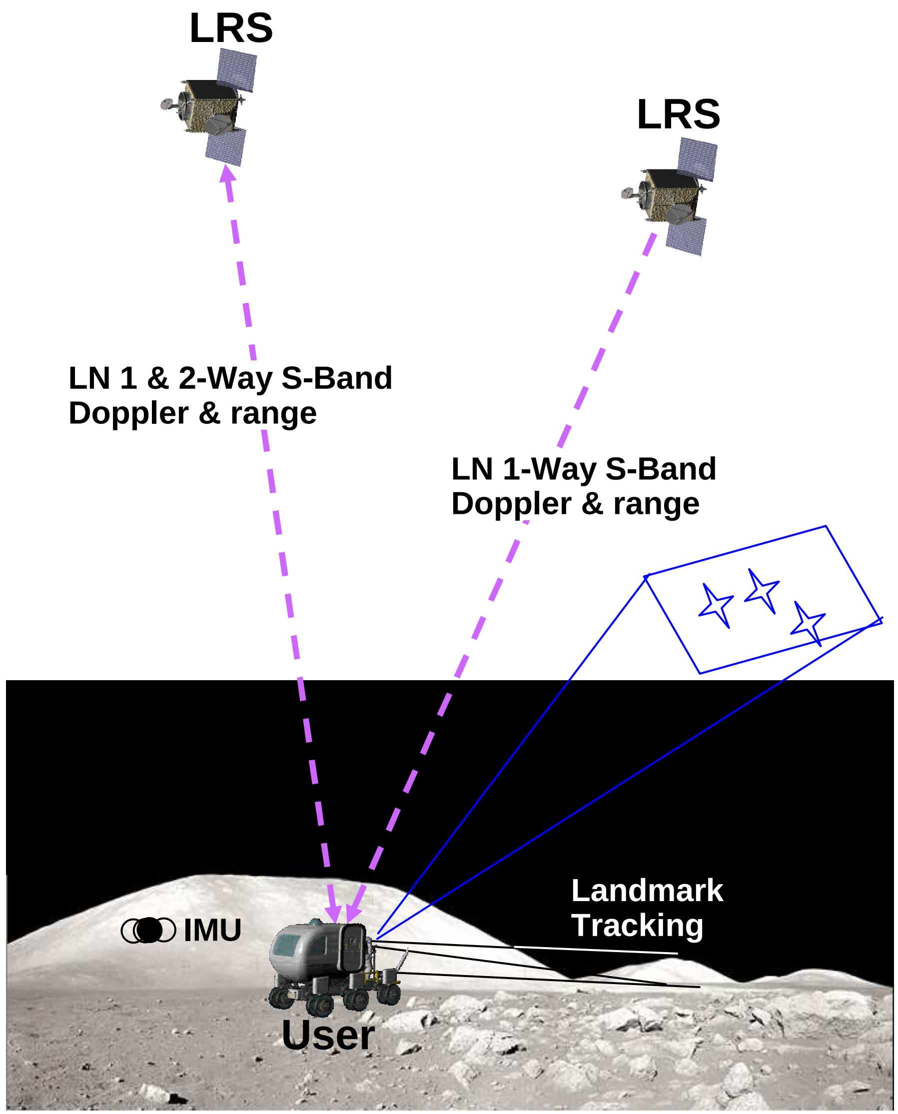
Descent & Landing Navigation

- **Autonomous Landing Mode (Ambient Lighting):**
  - ALHAT-based landing without active optics provides a self-contained system with IMUs
  - Designing to 100 m (3-σ) level landing accuracy assuming no emplaced infrastructure (i.e., relays)
  - Passive optical system + strobe lights for use in the last 300 m for low light landing situations
  - IMU data required for thrust level sensing
  - All data (RF, Optical, LIDAR/RADAR and IMU) processed in real-time for continuous trajectory update to closed-loop guidance system
- **Infrastructure-aided Landing Mode:**
  - LN-aided descent/landing augments a passive optical-based landing system by providing accurate radiometrics to maintain trajectory knowledge through powered descent and landing in view of emplaced landing aids
  - Anticipate 1 meter level landing accuracy
  - Landing aids near outpost are a combination of passive optical devices and LCTs that operate like the LRS
  - Radiometrics disciplined by an atomic clock



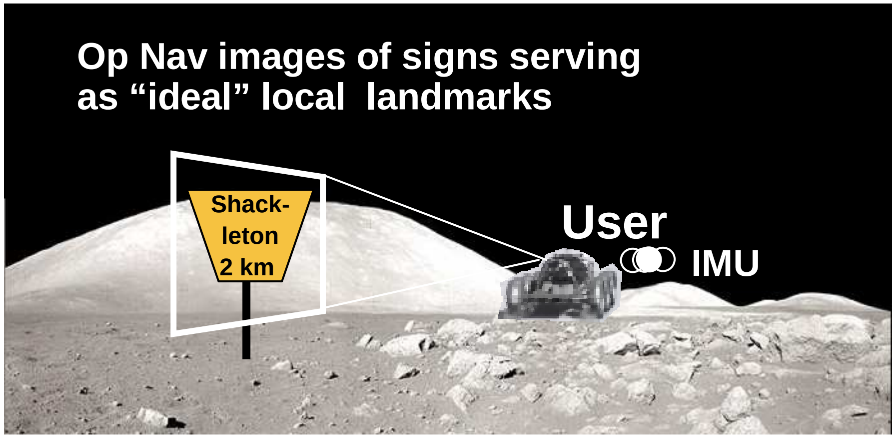
Surface Mobility Excursion Navigation

- **Surface mobility may involve excursions that are 500+ km from the outpost**
  - Farside trek has no DTE or LCT
  - Position knowledge $\leq$ 30 m needed to navigate to desirable spots and back home
  - IMU insufficient for in-situ navigation (1200 m long term accuracy)
- **LN tracking and imaging required**
  - Roving navigation requires periodic stops to obtain in-situ static position fixes ~every 30-60 min
- **In-situ static positioning fixes require**
  - LN radiometric tracking to obtain inertial position
  - Landmark tracking coupled with star tracking to obtain map relative position
  - Combined process resolves the 'map tie' error between inertial and map relative solutions
  - Static position to < 10 m in a few minutes
- **Roving navigation is initialized via the static position fix and then continues with real time navigation processing**
  - IMU data is dead reckoning velocity
  - LN radiometric tracking to solve for position and velocity and 'disciplining' IMU drift
  - Image data not taken while roving



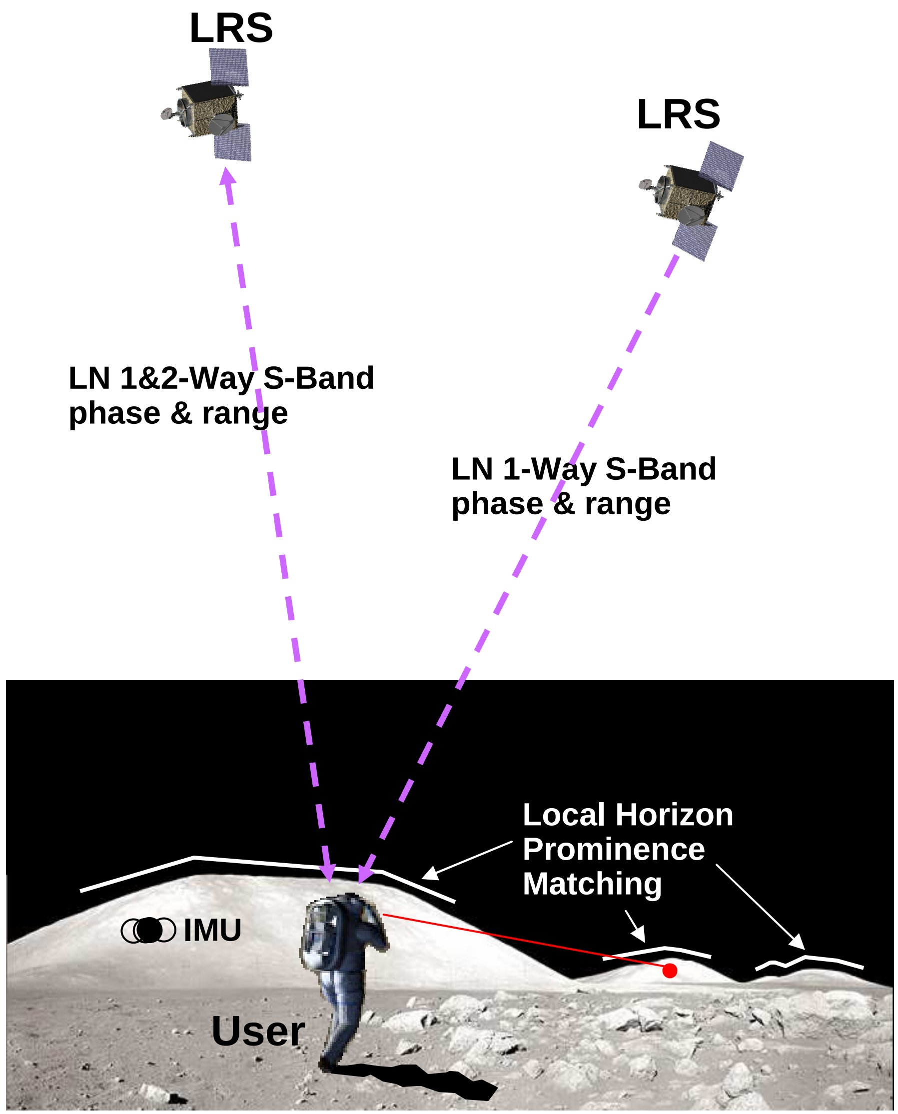
Outpost Surface Mobility Navigation

- **Surface mobility navigation at the outpost will require sub-meter class *relative* positioning**
  - **Crewed navigation uses ‘road rules’ for well traveled paths**
    - **Use well traveled paths so roads and signs can be used at little cost to achieve meter level performance**
  - **Robotic navigation combines ‘road rules’ with optical imaging road signage with unique visual markers**
    - **Autonomous rovers use combination of wheel odometry and narrow angle cameras to image visual markers for relative navigation**
    - **Need autonomy to handle ‘rules of the road’ for collision avoidance with obstacles/other rovers**
  - **Radiometrics useful in this application if there are 3 LCTs/LRSs in-view that can be ranged & triangulated**
    - **Meter-class positioning possible with this arrangement; however above markers and road-rules should be sufficient**



Off-nominal: Astronaut EVA Walkback

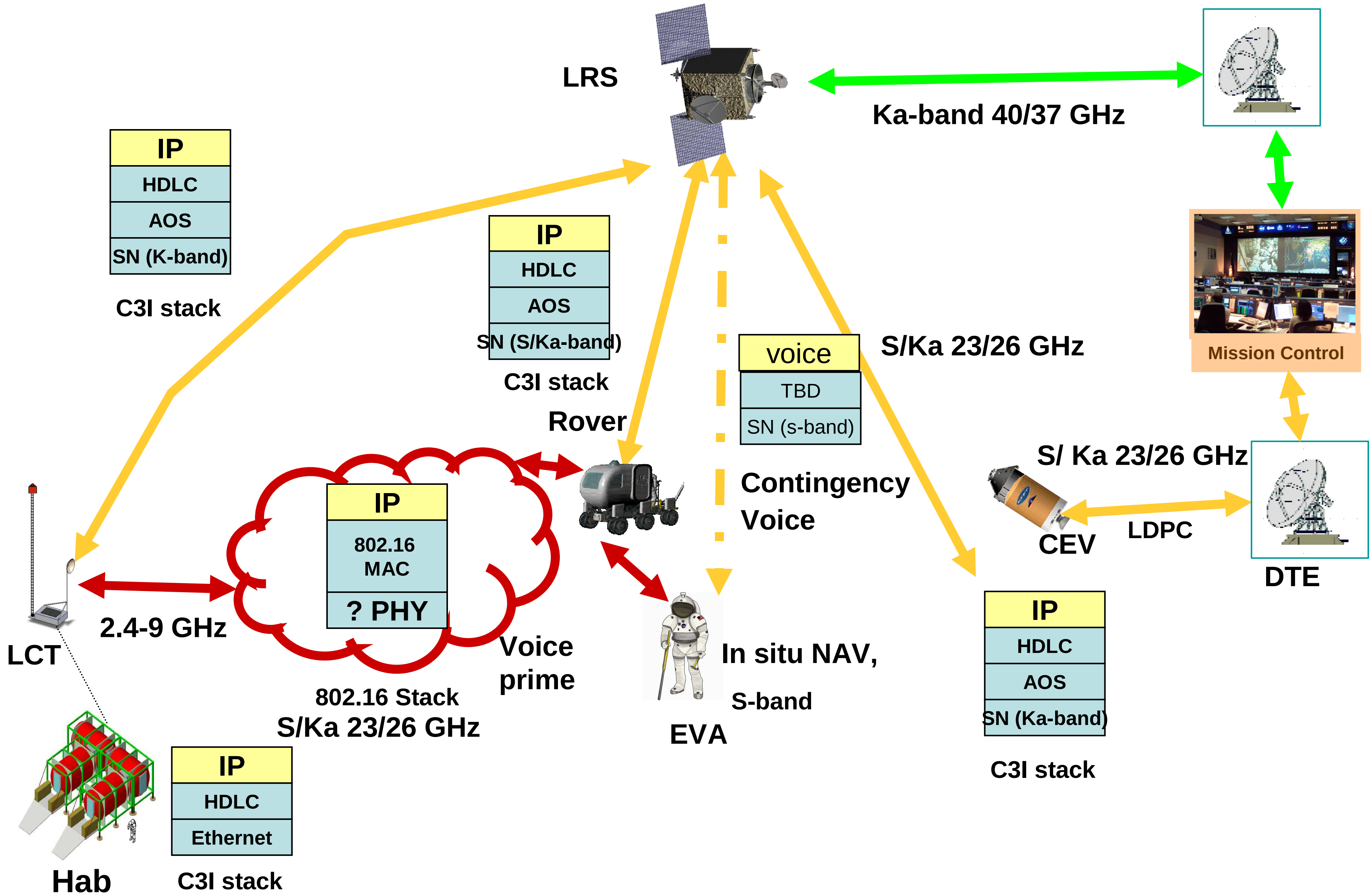
- Similar to the extended excursion Surface Mobility case except:
  - 2-Way radiometrics from LN; multiple access is via switching between in-view LRSs
  - Crew may be out of contact with rover
  - MEMs IMUs embedded in astronaut suit
    - Unaided IMU accuracy > 1 km error
  - EVA radio is lightweight, low power omni with a less capable oscillator
  - DTM may be embedded in a hand held computer
  - Hand held low-res (binocular style) horizon prominence matcher for local terrain should provide limited range 50m class positioning
- System performance degraded from the rover capability
- Safe enough for a walk back to a designated site?
- Exploring caves & lava tubes will require additional methods



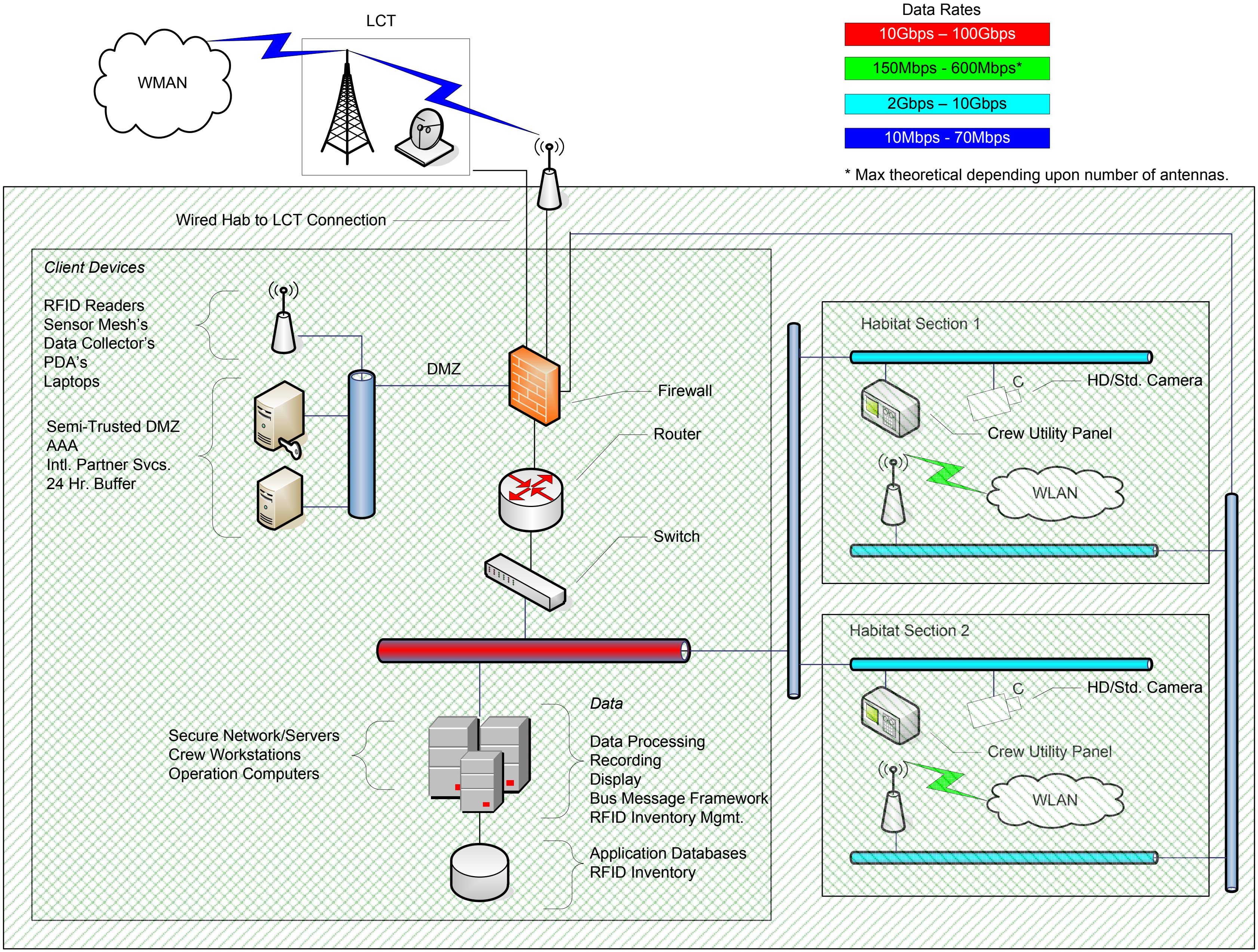
User Radios – Product Line

- For commonality, C&N designed a set of radios to meet the needs of all other Focus Elements. To minimize non-recurring & recurring unit cost, all radios use common technology & components wherever possible. Three types were defined:
- Fixed Base User Radio
  - Power-efficient mini-LCT sized for five simultaneous users.
  - Supports operations remote from LCT anywhere on Moon, e.g. ISRU in crater, nuclear power behind a hill, Sorties, Mobile Lander, man-tended Science cluster.
  - Creates WLAN sub-node fully connected to LN providing Ka & S-band antennas to close link to LRS or Earth.
- Mobile User Radio for Rovers
  - Normal mode in line-of-sight of LCT or Fixed Base, provides high rate data via 802.16e cell phone plus omni S-band 2-way navigation.
  - Self-Sufficient mode for remote operations, provides Ka & S-band antennas for Rover to communicate via LRS or Earth, and forward data from EVA Crew.
- EVA Suit Radio
  - Designed to meet 2 kg and 0.25 W transmit power Suit limits.
  - Provides high rate 802.16e cell phone service to LCT or Rover; Rover provides navigation.
  - Contingency walk-back scenarios - Supports 8 kbps contingency voice to LRS on S band as well as 2-way navigation.

Surface Architecture – Network Protocols



Internal & Wireless Comm: Lunar Habitat Network



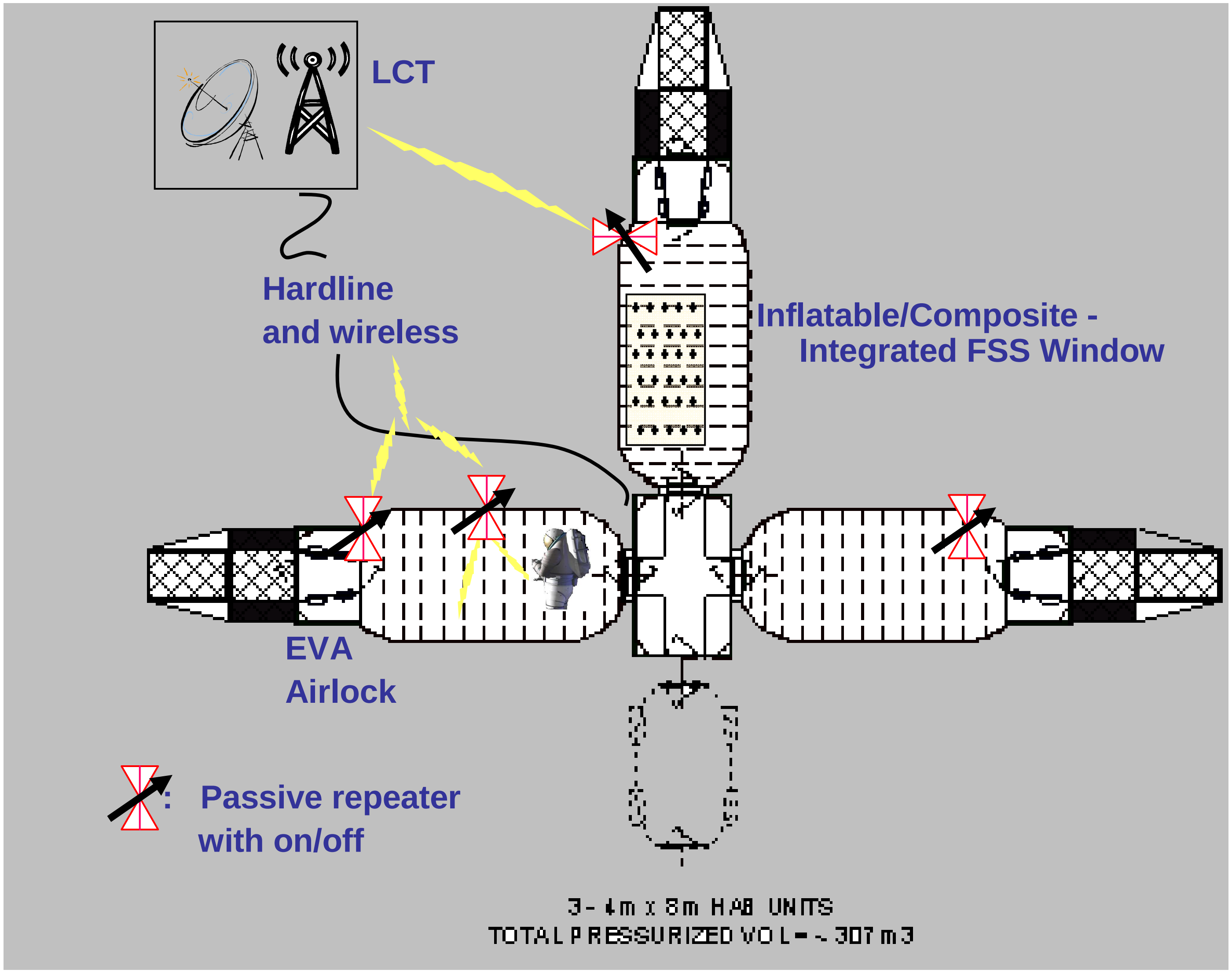
Lunar Habitat Network Conops (1)

- Transports 3 types of traffic: voice, video, data
- All IP communications from or to the Habitat are routed through the LCT
  - Wired
  - Redundant wireless link
- Assume high level of autonomy / low level of ground support
  - Distributed intelligence is leveraged to minimize ground support and unnecessary traffic within the habitat and from habitat to ground.
- The architecture is scalable by adding components.
- High design throughput rates permit high levels of growth without hardware upgrades
- Wired infrastructure
  - Core “Operations Center” wired network
  - Distributed wired network infrastructure
  - Existing higher rate standards-based network will be used if no cost/schedule impact

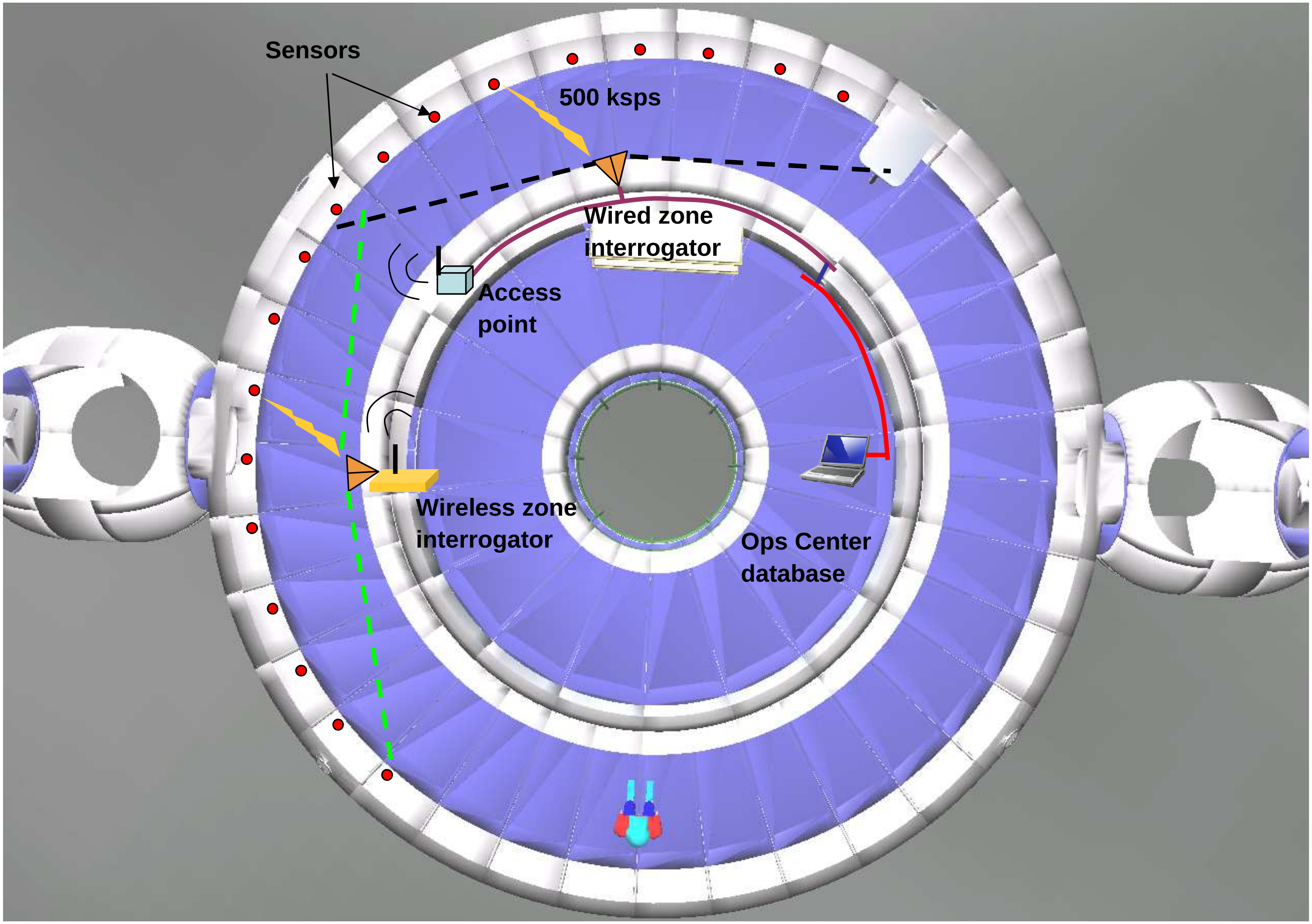
Lunar Habitat Network Conops (2)

- Wireless networks
  – Wireless Local Area Network (LAN)
  – RFID for inventory management, localization, and situational awareness
  – Sensor networks
  – Wireless Personal Area Networks (PAN)
- Separate distributed network through all Habitat sections carries “wireless-only” traffic to the firewall before entering the secured network
- Priority networking services: VoIP and IPTV are primary considerations for throughput requirements with real-time nature and limited tolerance to variations
  – Addressed by QoS
- Primary network devices
  – Crew Utility Panels (CUP), laptop, computer peripherals, RFID, wireless sensor networks, cameras, headsets, etc.

Habitat Network Conops: Internal EVA Suit Comm (1)



Habitat Wireless Sensors Conops (1)



Habitat Wireless Sensors Conops (2)

- The habitat provides wired and wireless infrastructures to support zoned sensor networks
  - Connection through wireless access points:
    - is considered for possible weight savings over wired
    - provides network access for sensor needs unknown at outset
    - permits empirical determination of optimal interrogator locations
- Distributed intelligence is heavily utilized to avoid requirements for high throughput.
- Active sensor networks provide mesh capability to assure connectivity from remote sensor nodes to zone base.
- Passive, wireless sensors are exploited to the extent permitted by the technology.
  - Relatively new, currently no standard
- Structural Health Monitoring (SHM)
  - Distributed intelligence is heavily utilized to avoid requirements for high throughput.
  - Inflatable or composite walls contain embedded wireless sensors for micrometeoroid impact detection (MMOD).
  - Some sensors in low-power or “sleep” mode (e.g., accelerometers and acoustic emission)

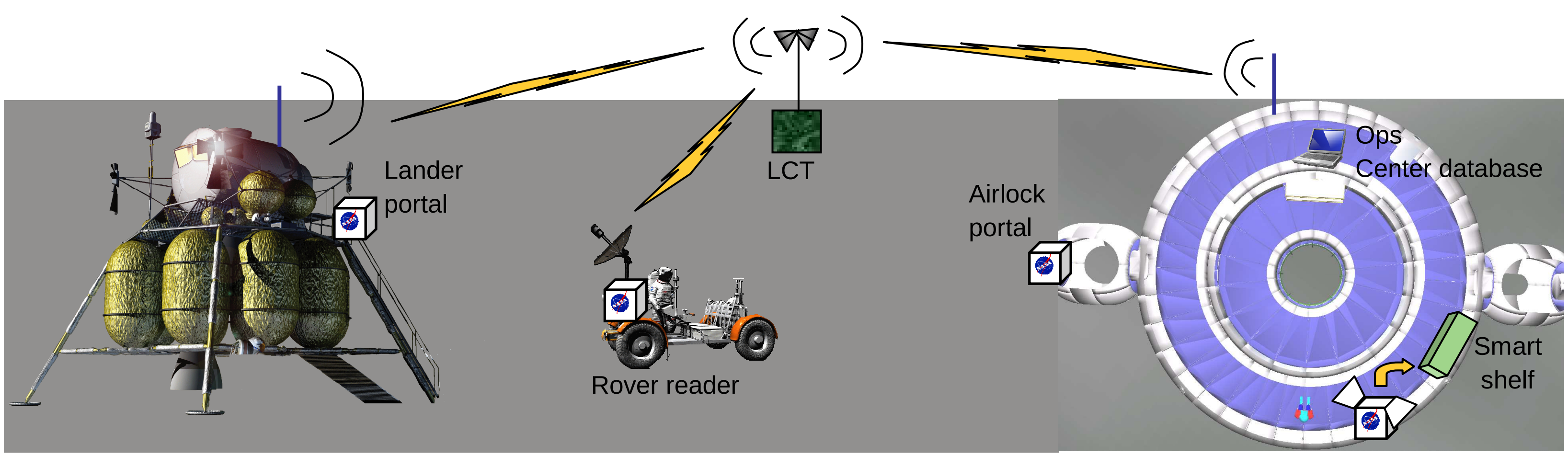
Habitat Wireless Sensors Conops (3)

- **Tools and Equipment**
  - **Sensor tags provide warning of environmental exceedances (e.g., shock, temperature)**
  - **In-Flight Maintenance (IFM)**
    - **Some IFM tools will utilize WLAN access**
    - **Handheld sensors (e.g., leak locators)**
    - **Active and passive sensors**
    - **Tool-mounted tags provide tool location and orientation (e.g., tip of borescope)**
    - **Possible strap-on tags**

RFID Use Cases – Vehicle Supply Transfers

2) Vehicle Supply Transfers

- **Objective: Accurate verification of supply transfers from any supply element to any vehicle.**
- **Ingress and egress of supplies are be tracked into and out of any major vehicle using portal-based RFID interrogation.**
- **Items are transferred in various forms (e.g., equipment, spares, LRUs, Cargo or Crew Transfer Bags (CTB), etc.)**
- **Vehicle transfers include: Ground-CEV; CEV-ISS; CEV-Lander; Lander-LSAM; Lander-Habitat; Lander-Rover**



RFID Use Cases – Localization & Inventory Audits

3) Intra-Habitat – Equipment/LRU

- Objective: Localize equipment and LRUs
- Portals or zone interrogators track equipment ingress/egress from habitat sections and rooms.
- Scanned zone interrogator can provide real time tracking within coverage area.

4) Intra-Habitat – Inventory Audits

- Objective: Automation of inventory management and localization
- Provide audit capability of supplies, consumables, and equipment
- Opportunity for significant decrease in crew labor
- Capability needs to be in place at the outset

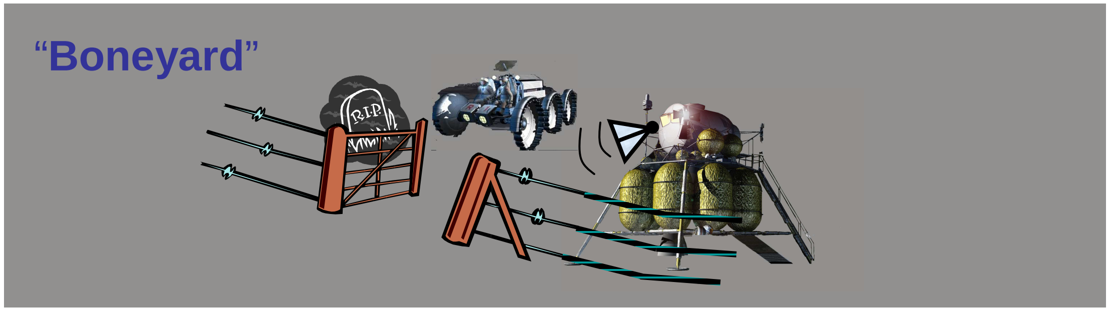
Stack of ISS Cargo Transfer Bags

RFID Use Cases – Consumables & Medical Supplies

5) **Intra-Habitat - Consumables**
   - Objective: Augmentation for inventory management and situational awareness.
   - Packaging on consumables contains RFID tag
   - Refuse container interrogators read package tag and update item inventory and kills tag
   - RFID database application provides warning if product expires before item appears in trash
   - Range < 1 ft.
6) **Intra-Habitat – Medical supplies**
   - Objective: Inventory management, localization, and situational awareness
   - Inventory management for medical instruments, supplies, and pharmaceuticals.
   - Provide expiration warnings, particularly for pharmaceuticals.
   - Provide verification or warning relating to missed administration, or dosage, of medications.
   - Range < 1 ft.

7) Habitat Proximity Asset Localization

- Objective: Inventory management, localization, and situational awareness
- Provides rapid localization of external assets, equipment, and tools between habitats, tool crib, SMUs, rovers, boneyard, etc.
- Larger ranges, up to and possibly exceeding 200 ft.
- Reader type: portal, vehicle mounted, scanned, and/or fixed beam
- Gatekeeper: zone or portal interrogator monitors boneyard
  - Spent elements serve as repository for parts
  - Gatekeeper is powered by, and possibly located on or near, spent Lander

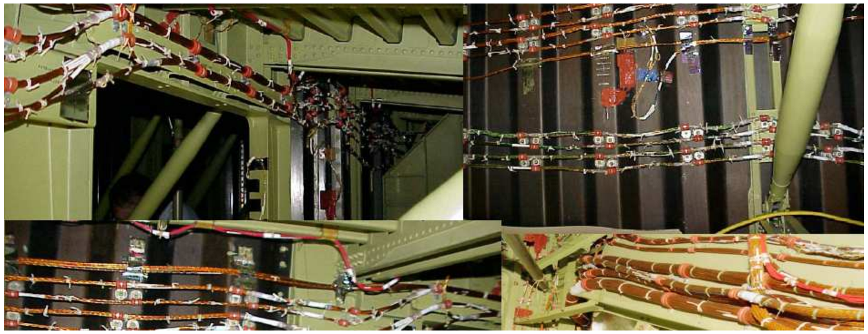


RFID Use Cases – Part Identification

8) Identification of element/vehicle/habitat parts

- Objective: immediate recognition of multitude of parts and association to database
- Description: tags on element parts (e.g., wires) provide immediate identification and association with database description, connectivity, calibration information, known location, part history, wire time domain signatures, etc. This tag would typically be accessed by a portable, handheld interrogator.
- Range: near-field (< 1 ft)
- Reader type: portable (handheld)
- Readability: 100%

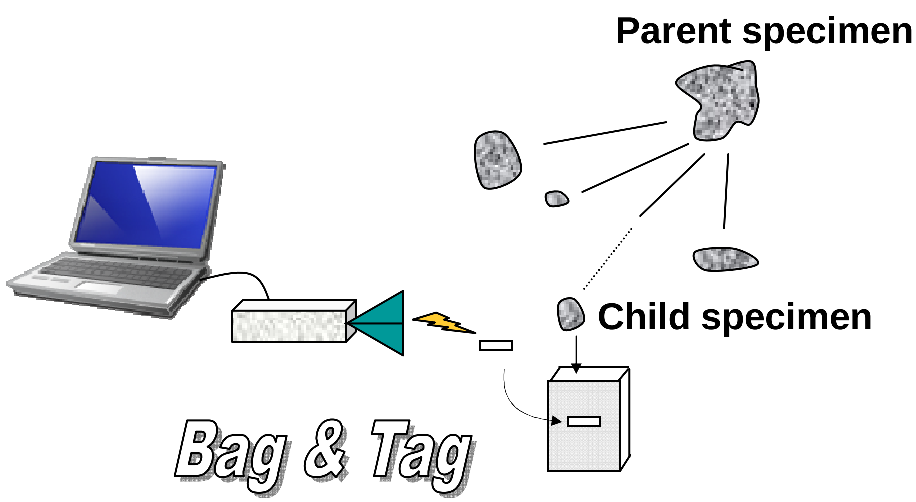
Wiring Inside Shuttle Columbia Wing [10]



RFID Use Cases – Science Sample Inventory Management

9) Lunar Surface – Science geologic sample inventory management

- Objective: Track heritage (parent specimens)
- IM of lunar geologic samples in specimen bags
- Special: Requires on-site tagging (pre-printed tags or portable printer)
- Range: 2 – 5 ft (portable)
- Read rate: 100%



<u>RFID-Enabled Specimen Tagging Process</u>

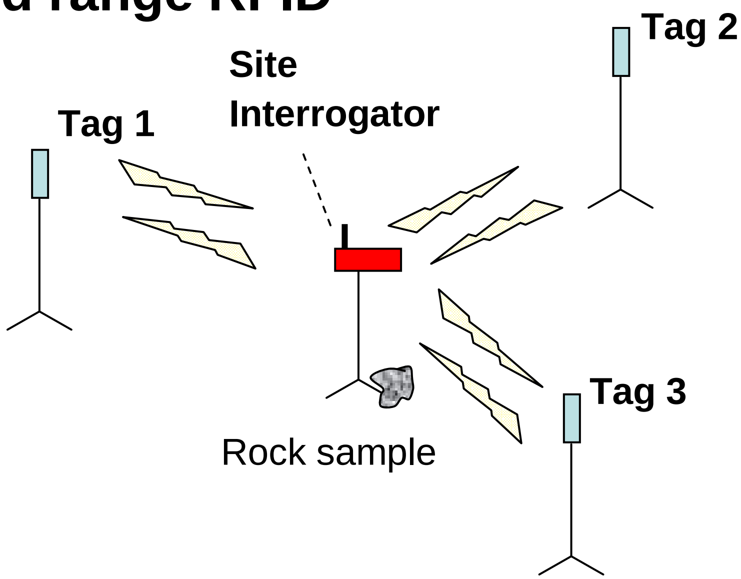
User enters "New Parent Specimen"

- **Grab and read RFID tag**
  - **Tag ID is stored as "Parent *M*"**
  - **Parent location coordinates:**
    - Auto-association with ID (see "sample tracking" case use)
- **Place parent tag on parent bag**
  - **Break off child *i* specimen**
  - **Grab and read RFID tag**
    - (database associates ID with Parent *M*)
  - **Stick tag on child *i* bag**
  - **Repeat for child *i* + 1**
- **Repeat for next Parent *M*+1**

10) Lunar Surface – Science Sample Position Determination

OPTION 1: Passive RFID tags

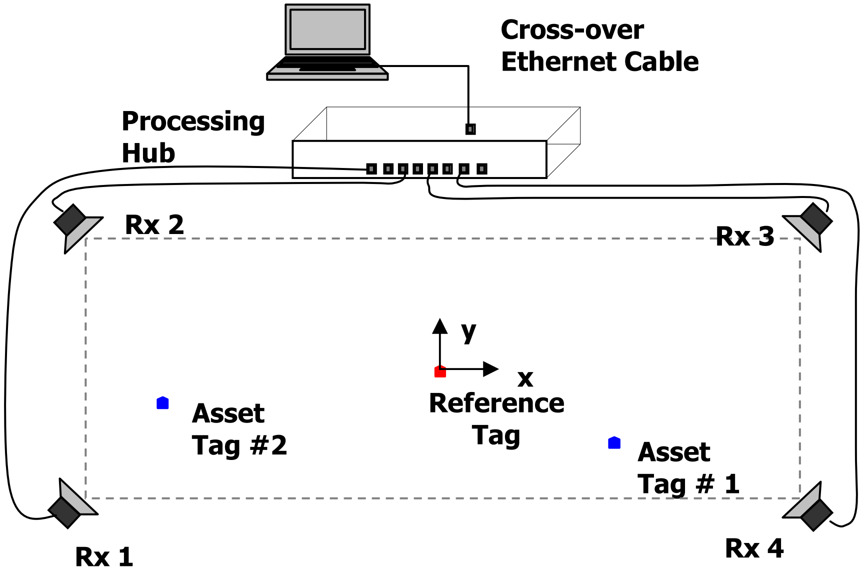
- Objective: Provide absolute location of samples within 1 m
- Dependent upon other means to accurately survey boundary tag positions.
- Special: Requires interrogator (at sample site) + local survey of 3 tags for triangulation.
- Survey tags require extended range RFID
- Range: 150 ft (TBR)
- Read rate: 100%

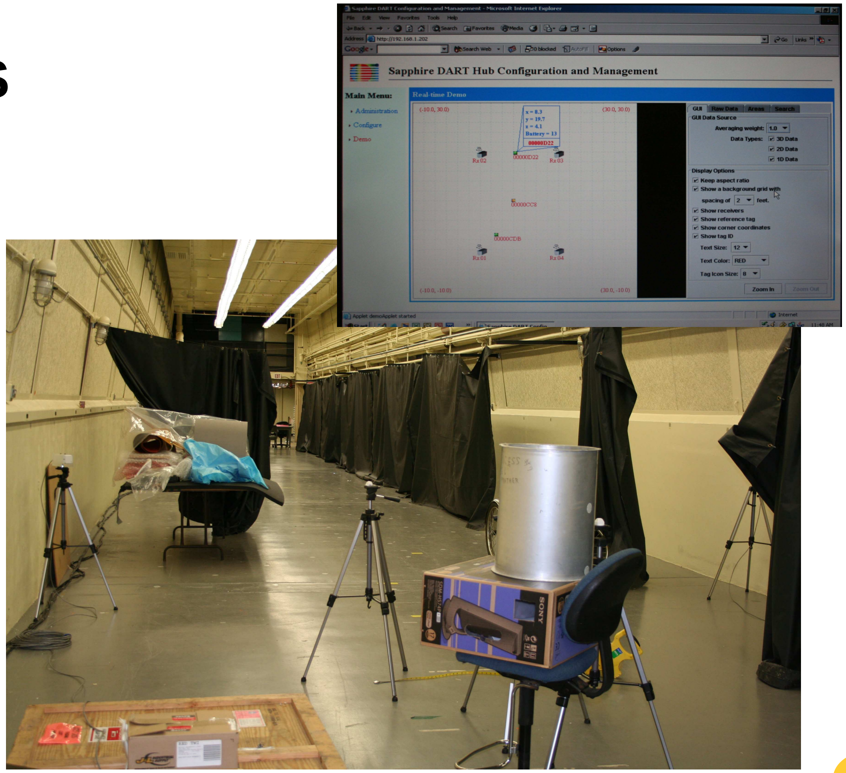


11)Lunar Surface – Science sample tracking

OPTION 2: Active UWB RFID tags

- Objective: Provide absolute location of samples within 1 m
- Demonstrated accuracy +/- 10 cm.
- Special: Requires interrogator (at sample site) with 4 antennas + local survey of 4 interrogator antennas for triangulation.
- Range: 400 ft
- Reader: custom COTS
- Read rate: 100%





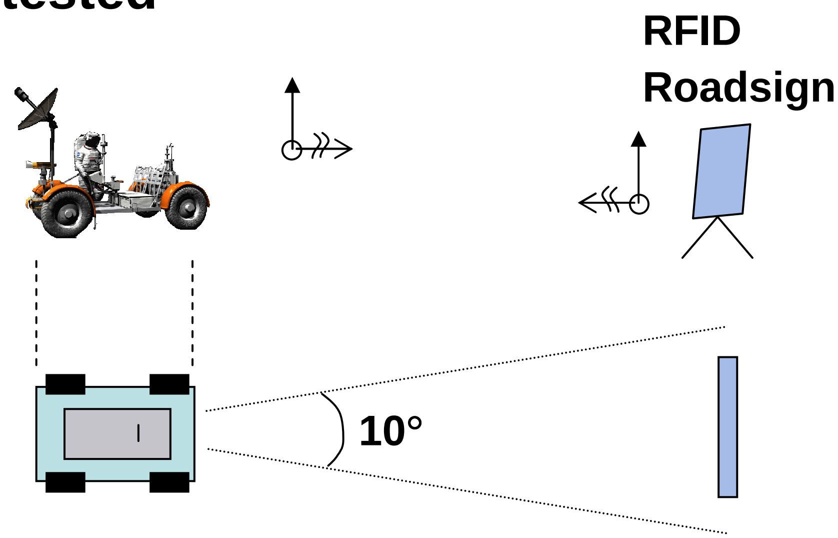
RFID Use Cases – Lunar Road Sign

12) Lunar Road Sign

- Objective: Provide rover with road sign ID and range
  - Range >> than permitted by human vision
- Rover is equipped with RFID interrogator and antenna of moderate to high directivity; e.g., 22 dBi.
- Enhanced passive RFID tags are positioned as road signs upon initial excursions.
- Low TRL: Has not been fully tested

Estimated Link Parameters

- Frequency: 2.4 GHz
- Sign dimensions: 59 cm x 59 cm (23 in)
- Gain (interrogator): 22 dBi
- Transmit power: 100 mW
- IF BW: 500 Hz
- Range: 518 m (1700 ft)
- Estimated SNR: 15 dB

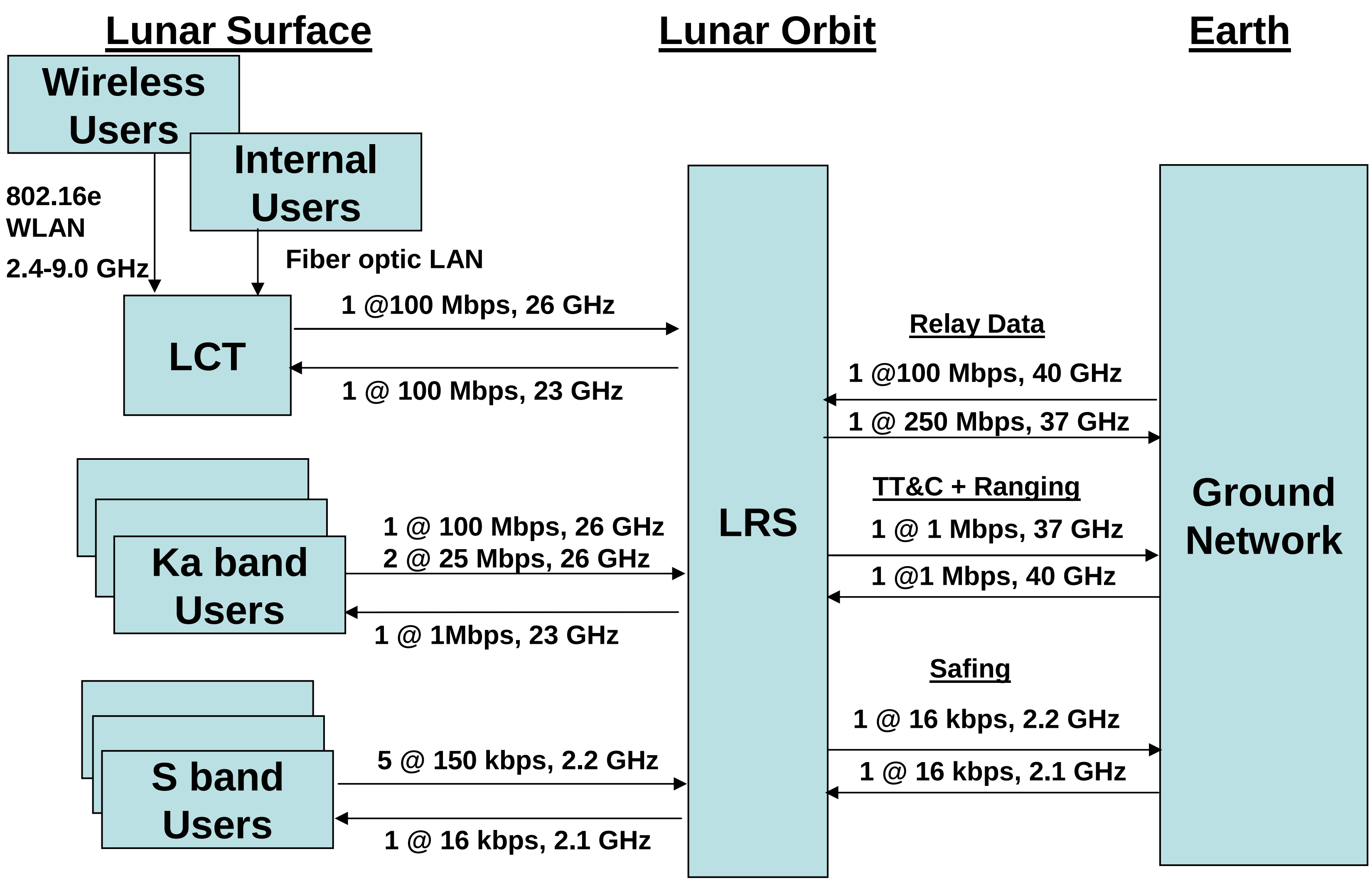


Aggregate Information Rates Summary

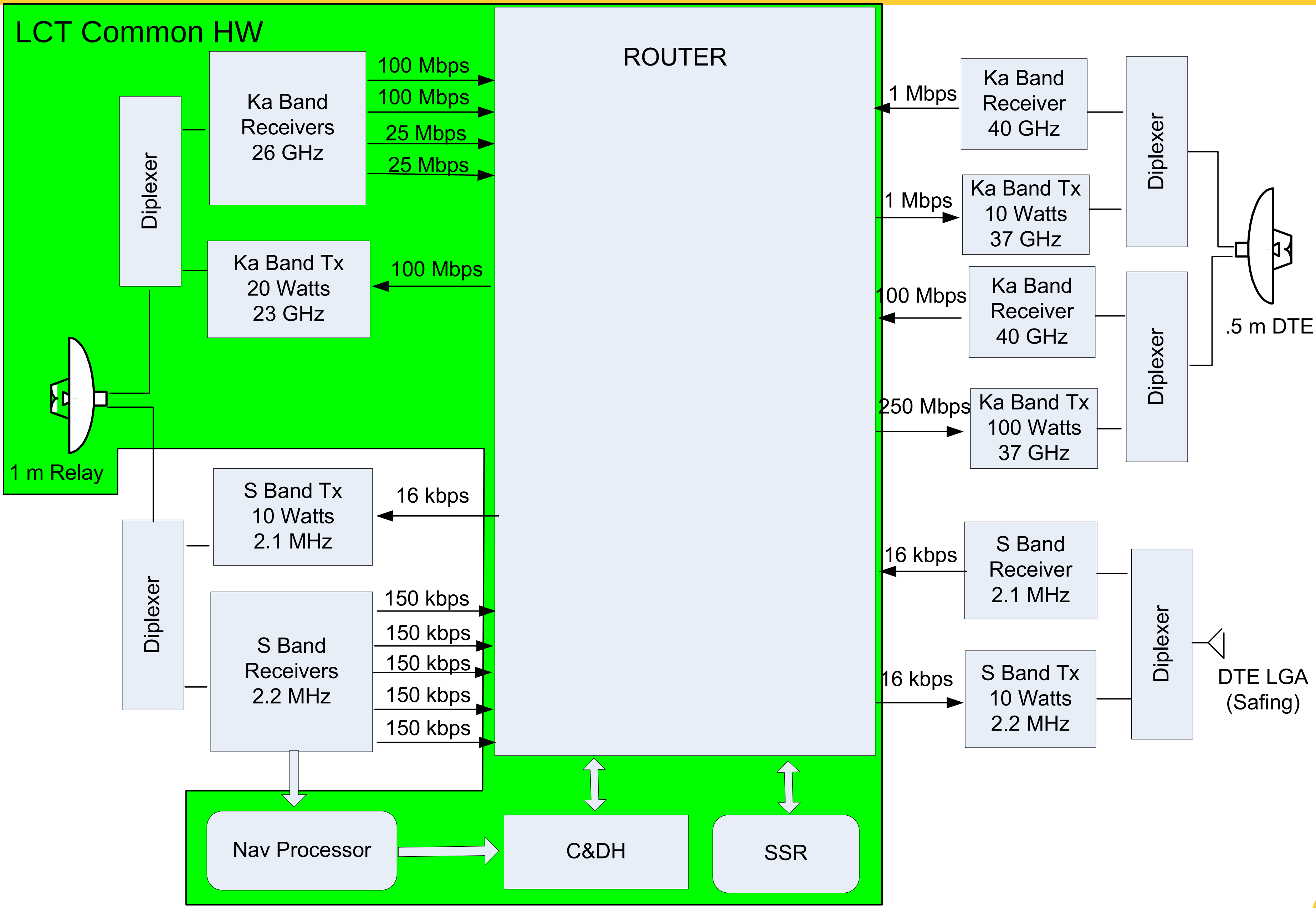
Description	Applicable System(s)	Aggregate Information Rates (without explicit margin added)		
		Low Rate (Mbps)	High Rate (Mbps)	Total Rate (Mbps)
Aggregate Peak Rate to Earth	LRS and Earth Ground System	3.9	151.0	154.9
Aggregate Peak Rate from Earth	LRS and Earth Ground System	1.1	66.0	67.1
Aggregate Peak Rate Up to LRS from Lunar Surface	LRS and LCT	6.4	216.0	222.4
Aggregate Peak Rate Down from LRS to Lunar Surface	LRS and LCT	6.1	141.0	147.1
Aggregate Peak Rate Across Lunar Surface	LCT	8.7	143.0	151.7

- The aggregate peak rate to and from Earth will occur between the LRS and the Earth Ground System and will have to be apportioned between S-band and 37/40 GHz band links.
- The aggregate peak rate up to LRS and down from LRS relative to the lunar surface will have to be apportioned between the S-band and 26/23 GHz band links occurring between:
  - LRS and LCT (when all surface elements are in sight of LCT)
  - LRS and LCT + mini-LCT + Mobile User Radios + EVA Suit Contingency Comm
- The aggregate peak rate across the lunar surface pertains to the 802.16 capacity of the LCT when all surface elements are in sight.
- Traffic Model is not based on detailed operational scenarios. Realistic scenarios could limit total rates, e.g., by deferring non-time critical data to off-peak times.
- Overhead due to protocols, coding and modulation is not included.

LRS Comm Payload Connectivity



LRS Data Flow

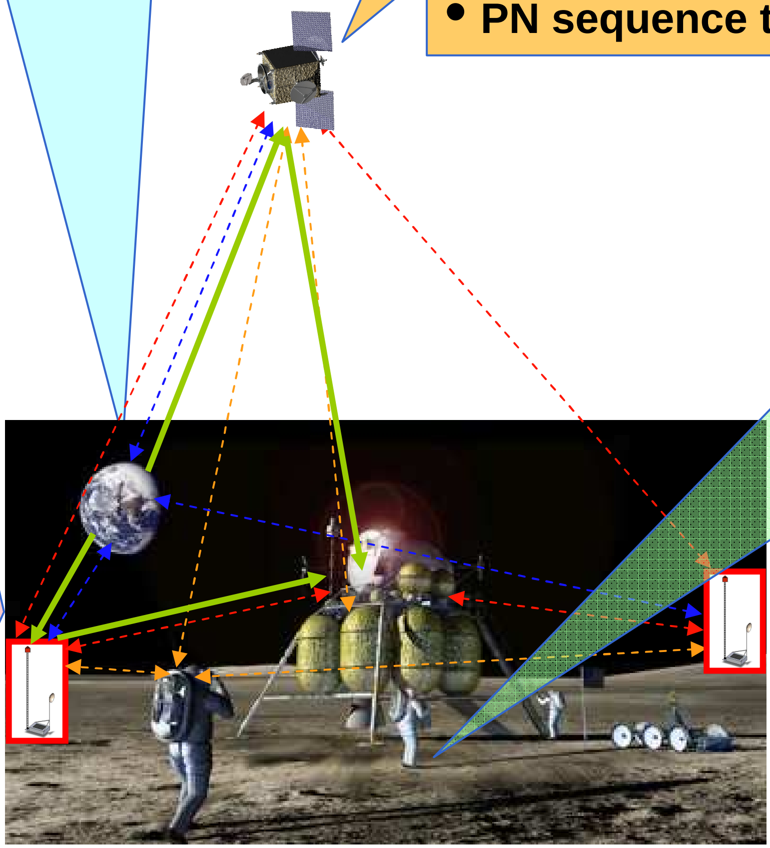


LN Radiometric Time Architecture

Earth
- Maintains common time base
- Initiates 2w radiometrics w/LRS & Lunar surface elements
- Produces Navigation Message

LRS Transceiver
- Atomic Time & Frequency standard
- Disseminates Navigation Message on Tx forward link
- Radiometrics can be initiated & measured for 2w, telemetered to user
- Radiometrics can be initiated @ LRS and measured by user for 1w
- PN sequence tied to epoch

LCT Transceiver
- Atomic Time & Frequency standard
- Disseminates Navigation Message on Tx forward link
- Radiometrics can be initiated & measured for 2w, telemetered to user
- Radiometrics can be initiated @ LRS and measured by user for 1w
- PN sequence tied to epoch



User (Lander, Rover, EVA)
- USO to wrist watch
- Transponder* (multiple Rx: 2w to one element, 1wF from all others)
- Demodulate Navigation Message
- Radiometrics can be measured from LRS & LCT forward signals

* Transceiver if only 1w needed

Agenda

- Context for Change
- Lunar Network in the context of Exploration Systems
  - Communications
  - Navigation
  - Networking
- Lunar Network in the context of Science's International Lunar Network
- Lunar Network in the context of NASA's Integrated Network Architecture
  - Communications, Navigation & Networking Services
  - Integrated Service Portal
  - Commercial & International Partnering
- Conclusion
- SE Challenges

ILN Anchor Nodes
Science Definition Team (SDT) Charter & Recommendations

Lunar Science

SDT Charter

Address science uniquely enabled by a lunar network by establishing the priority of science & measurement goals; defining the science "floor" and "baseline" missions

The ILD SDT was co-chaired by Joe Veverka & Barbara Cohen

ILN Mission Goal

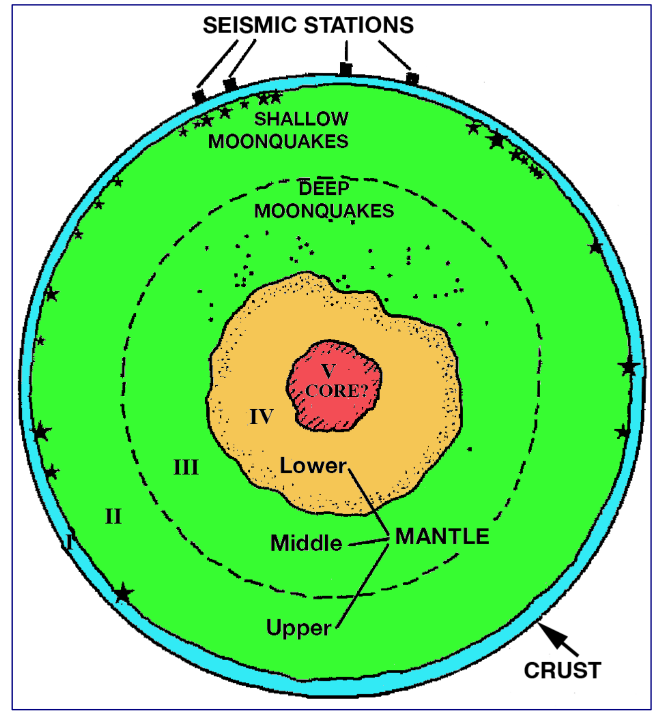
To understand the interior structure and composition of the moon; fundamental information on the evolution of a differentiated planetary body.

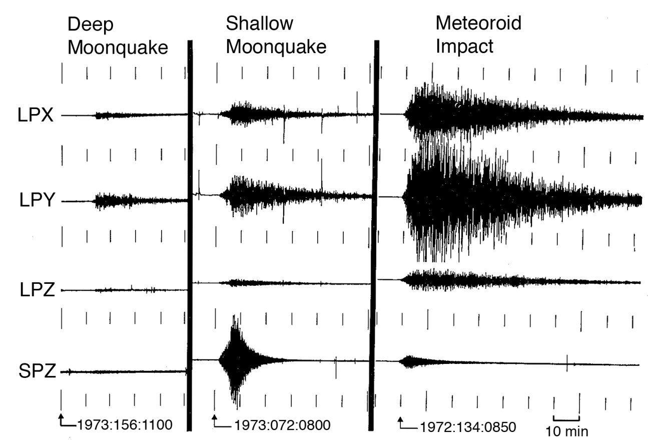
ILN SDT Recommendations

Perform four prioritizes science investigations: seismometry, direct heat flow measurements, electromagnetic sounding & laser ranging

Obtain complementary geophysical data from a network of at least four nodes operating simultaneously & continuously for 6 years (1 lunar tidal cycle)

Minimum science (direct investigation of the lunar core) can be accomplished with 2 nodes, carrying seismometers only, operating simultaneously & continuously for 2 years





ILN Anchor Nodes
Mission Overview

Lunar Science

International Lunar Network (ILN) Anchor Nodes

Objectives

- Establish 2 anchor nodes of an international lunar geophysical network
- NRC SCEM Science Concept 2- The structure and composition of the lunar interior provides fundamental information on the evolution of a differentiated body

Key parameters

- Launch 2013 / 2014, depending on resource availability
- Mass 150 Kg (estimate wet lander mass)
- Mission length: TBD (Network operation time is 6 years (to be refined)

Mission

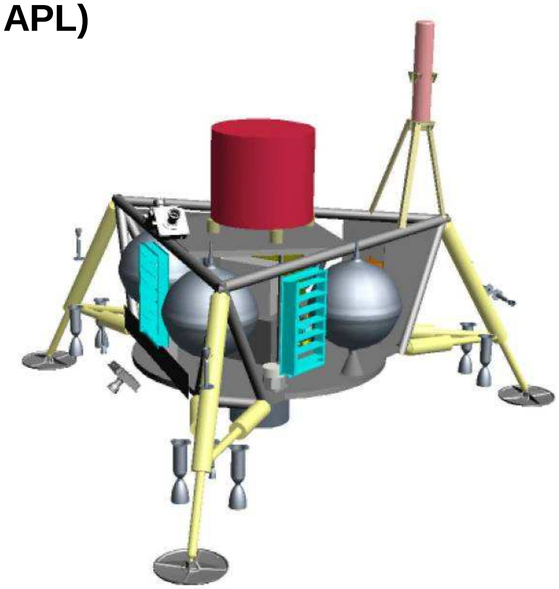
- Type: Small “Mini” Lander – Category III, Class TBD Depending on Architecture
- Spacecraft Bus Acquisition: Directed to MSFC (partnered with APL)
- Target $200M LCC with reserve
- Pre-Phase A Started in FY08

Instruments

- Instruments will be competitively selected
- Baseline Science
  - Seismometers
  - Heat Flow Instruments
  - EM Sounding Instruments
  - Laser Ranging experiments

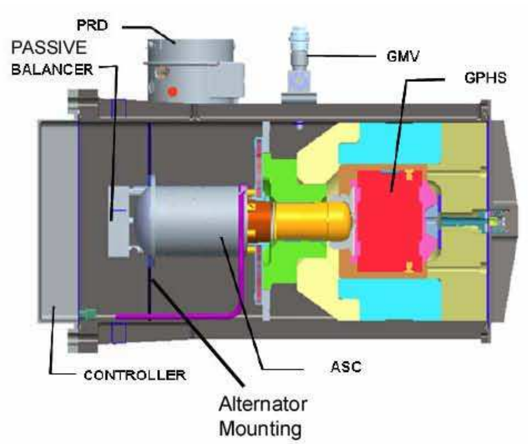
Flight Technology

- Small RPS
- Small High Performance Thrusters



LSP Flight Technology

Small RPS
Based on Stirling Technology

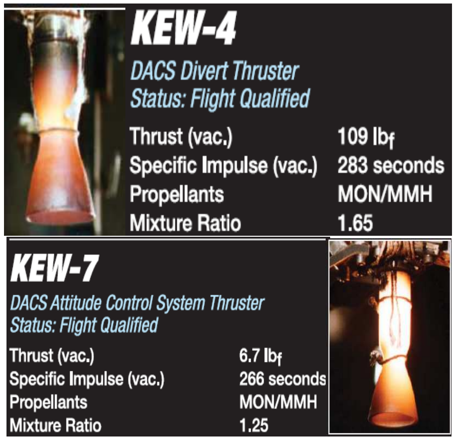


Advantage: Meets 60 We power requirement
Provides reduced power system mass to enable lowest mass lander

Risk: development schedule is undefined and may not support an ILN launch in the 2012 to 2014 timeframe

Risk Mitigated by use of full ASRG at ½ fuel load

Near-COTS DACS Thrusters

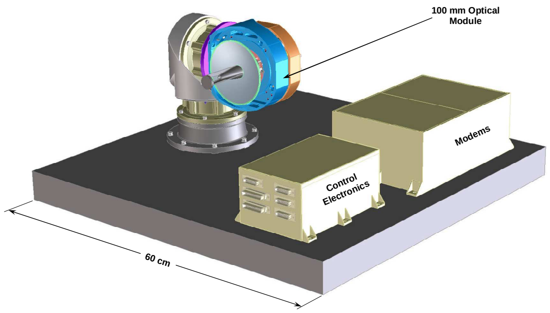


Advantage: High thrust-to-weight ratio thrusters enable lowest mass lander and less thermal energy requirements.

Risk: Using thrusters outside of qualification. Additional mass needed to remove heat for long burn. Limited thruster mod. and adv. development testing needed.

Risk Mitigated by early Qual test

Lunar Lasercom Demonstration (LLCD)



LLCD will demonstrate a high bandwidth space to ground link using a reliable optical terminal
51-622 Mbps xmt, 16 Mbps rcv

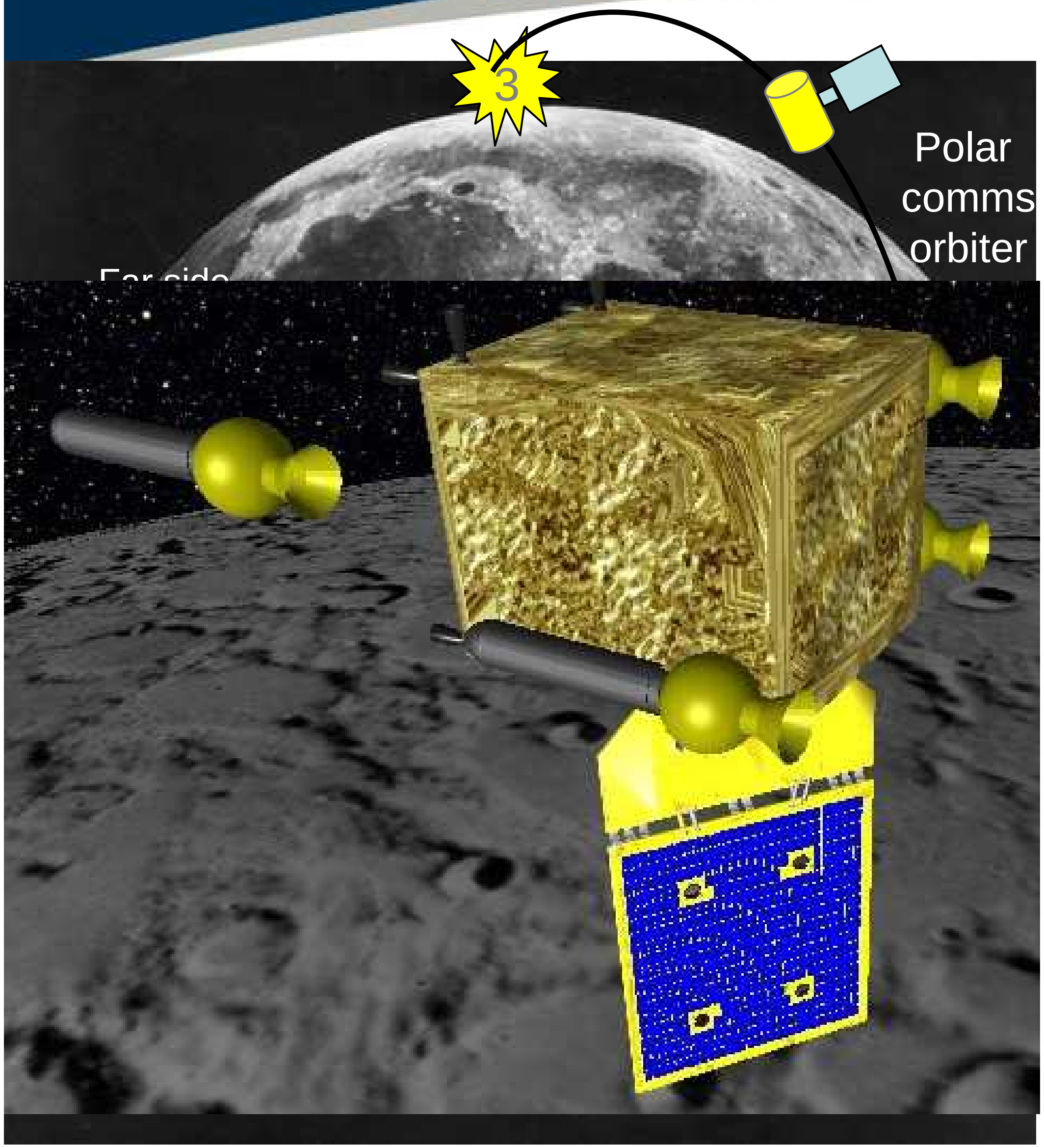
International Lunar Studies

- **Space Internetworking Strategy Group (SISG) developed Internetworking Roadmap coordinated with ESA, JAXA, & others**
- **Interagency Operations Advisory Group (IOAG) approved roadmap**
- **Interoperability Plenary (IOP) #2 approved Internetworking Roadmap**
  - **Joint Communiqué ratified by ASI (Italy), CNES (France), CNSA (China), DLR (Germany), ESA (Europe), ISRO (India), JAXA (Japan), NASA (United States) and RFSA (Russia)**
  - ***Resolution 3: IOAG organizational processes should be adapted to collect and process in a timely manner all the space communications and navigation requirements of other international space coordination groups (e.g., the International Space Exploration Coordination Group [ISECG], International Lunar Network [ILN], and international Mars exploration, inter alia), and to provide strategic guidance to the relevant standardization organizations (i.e., the Consultative Committee for Space Data Systems [CCSDS] and the Space Frequency Coordination Group [SFCG]).***
  - ***Resolution 6: The IOAG's Space Internetworking Strategy Group (SISG) should formalize a draft Solar System Internetwork (SSI) Operations Concept and candidate architectural definition in time for IOAG-13 and should prepare a mature architectural proposal for review and endorsement at the third Inter-Operability Plenary meeting (IOP-3). At that time, the IOAG is requested to present an enhanced service catalog for endorsement.***

International Lunar Studies

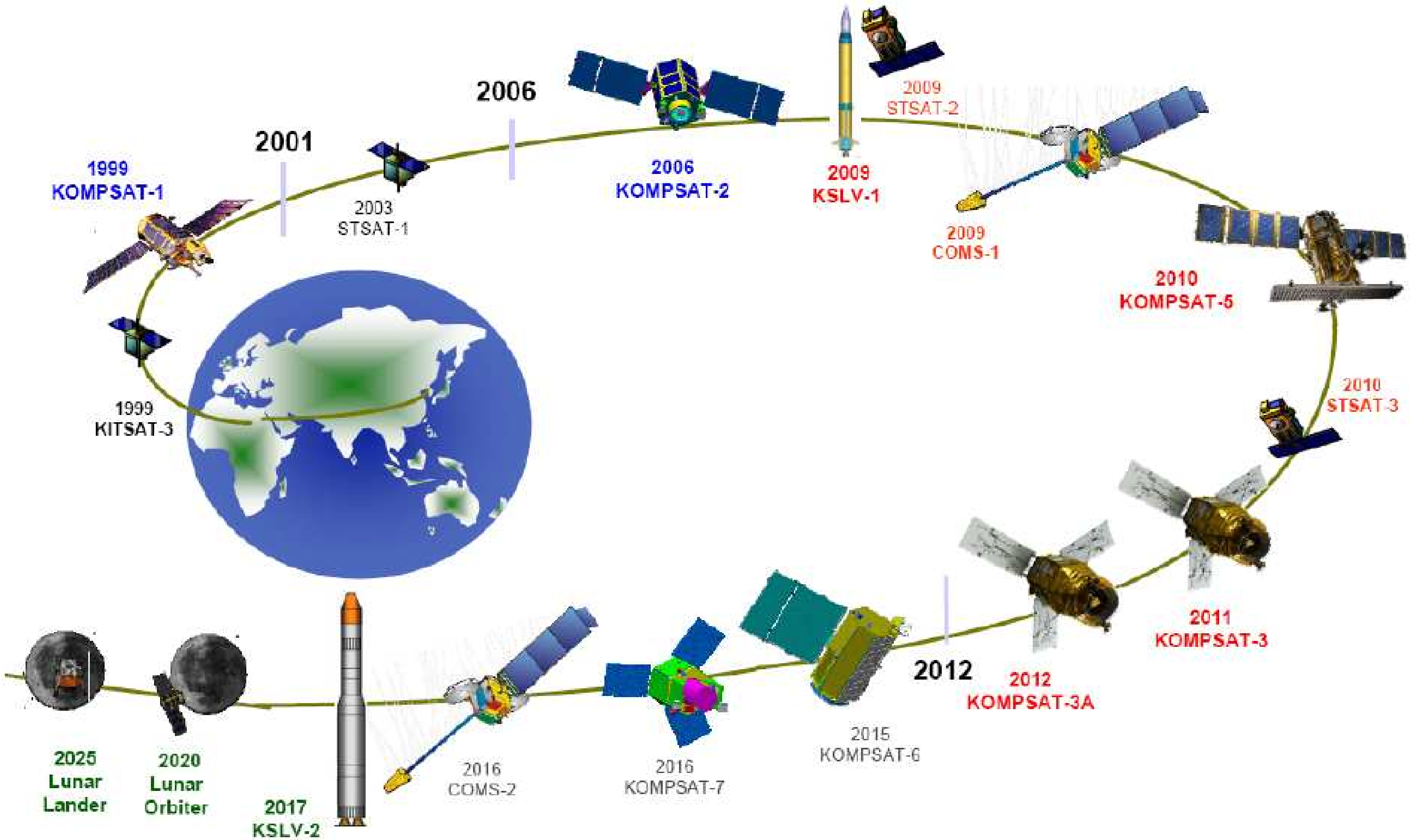
- Space Frequency Coordination Group (SFCG) established position on Lunar/Mars spectrum usage
  - Spectrum architecture should be consistent for ILN & Exploration
- Consultative Committee on Space Data Systems (CCSDS) held fall conference
  - Worked on standards important to CxP, e.g., LDPC
  - Lunar Surface C&N Workshop started identifying wireless standards needed
- Monthly telecons for ILN Comm WG
  - Members: ASI, BNSC, CNES, DLR, ISRO, JAXA, KARI, NASA
  - Fed scenarios into SISG internetworking roadmap
  - Received study reports from BNSC, DLR & KARI in Dec
  - Study report to Jim Green by January → ILN Steering Group in Feb

MoonLITE Mission Description



- **Delivery and Comms Spacecraft (Orbiter).**
  Deliver penetrators to ejection orbit.
  Provide pre-ejection health status,
  Provide relay communications.
- **Orbiter Payload**: 4 Descent Probes
  Each containing 10-15 kg penetrator + 20-25 kg de-orbit and attitude control system.
- **Landing sites:** Globally spaced
  Far side, Polar region(s), One near an Apollo landing site for calibration.
- **Duration**: >1 year for seismic network.
  Other science does not require so long (perhaps a few Lunar cycles for heat flow and volatiles much less).
- **Penetrator Design:** Single Body for simplicity and risk avoidance. Battery powered with comprehensive power saving techniques.

National Program Agenda



Schedule (TBC)

- Feasibility study finalization: by mid 2009
- Installation site selection: by 2011
- Vendor selection: by 2012
- Installation & Test: by 2016
- Validation & Ops: since 2017

22m Antenna by domestic firm, High Gain Antenna, Ltd

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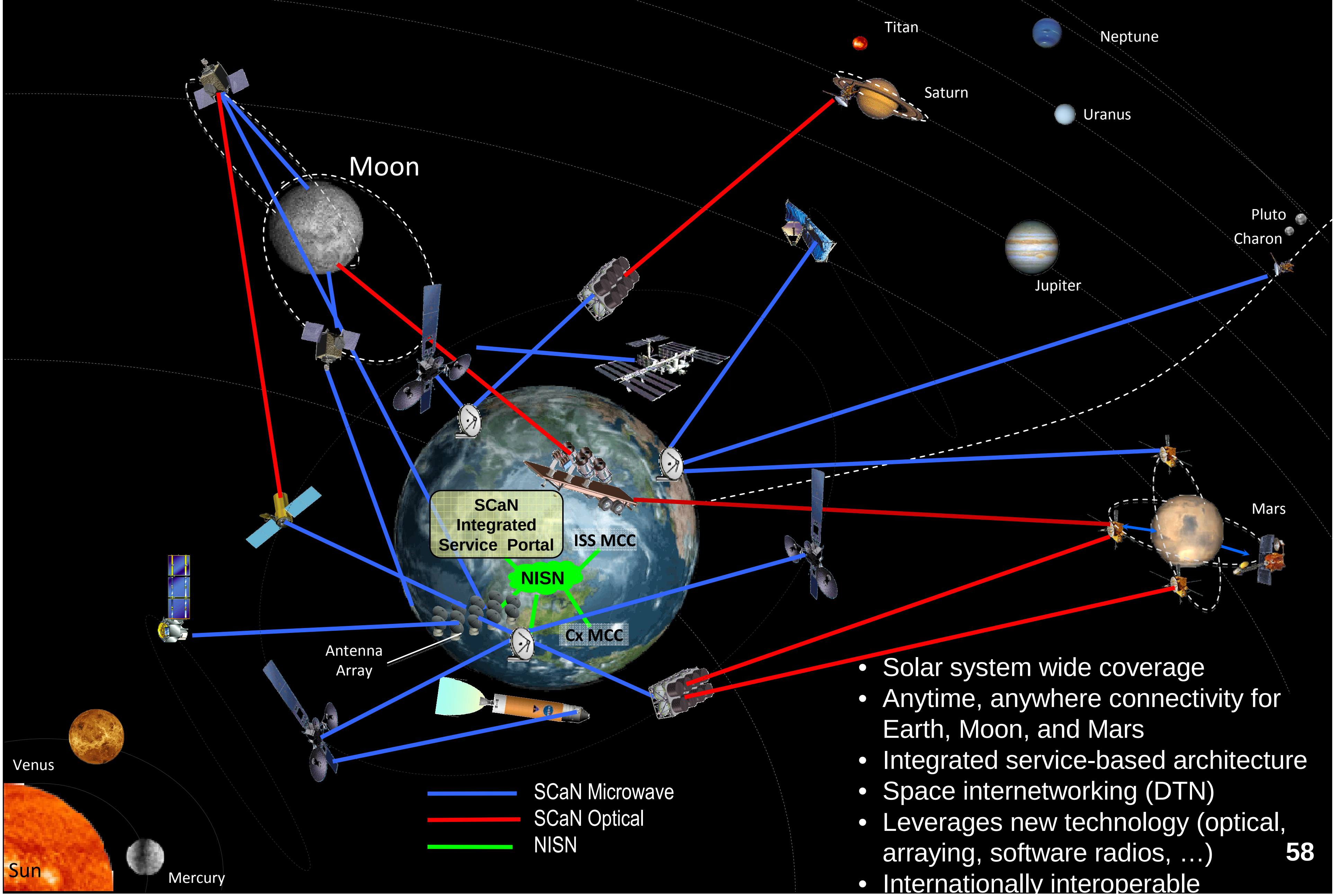
SCaN Notional Integrated Communication Architecture in 2025 Timeframe

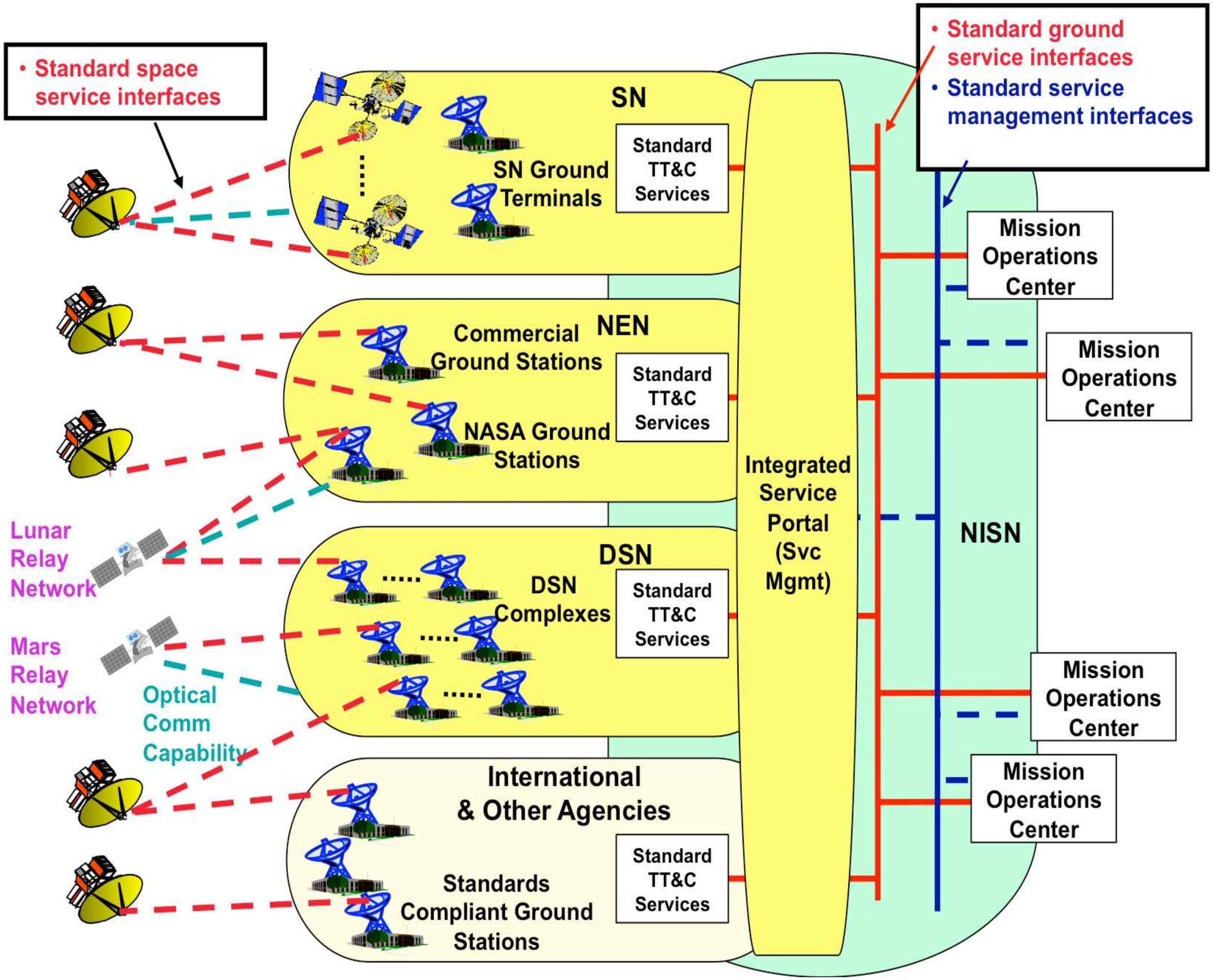


- Solar system wide coverage
- Anytime, anywhere connectivity for Earth, Moon, and Mars
- Integrated service-based architecture
- Space internetworking (DTN)
- Leverages new technology (optical, arraying, software radios, …)
- Internationally interoperable

SCaN Integrated Network Services

- **NASA SCaN infrastructure will provide four categories of standard services to its customers:**
  - **Forward data delivery services**
    - **Forward Command Link Transmission Unit (CLTU) service**
    - **Forward transfer frame service**
    - **Forward internetworking and file services**
  - **Return data delivery services**
    - **Return all frames service**
    - **Return channel frames service**
    - **Return internetworking and file services**
    - **Return unframed telemetry service**
  - **Radiometric services**
    - **Raw and Validated radiometric data**
    - **Delta- Differential One-way Ranging**
  - **Position and Timing services**
    - **Time distribution**
    - **Trajectory determination and prediction**
- **SCaN will continue to provide specialized services**

Integrated Service Architecture

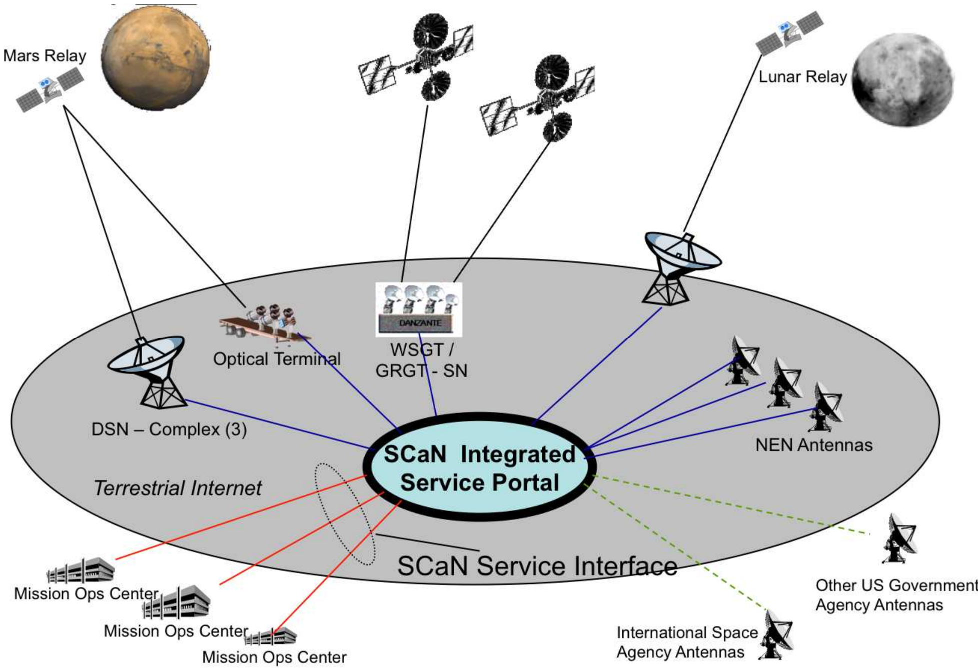


- **Services across networks migrate to open standards (CCSDS) for both Ops Center & Spacecraft interfaces**
- **Management services for mission planning, scheduling & execution standardized**

Integrated Service Portal (ISP)

Purpose & Benefits

- Maximize interoperability between SCaN networks & with partner assets
- Maximize commonality in service/network management among networks
- User benefits:
  - Reduces user burden
  - Lowers user mission cost especially by Center-leveraged commonality across their mission set
  - Standardizes service commitment process
  - Implements uniform security for TT&C

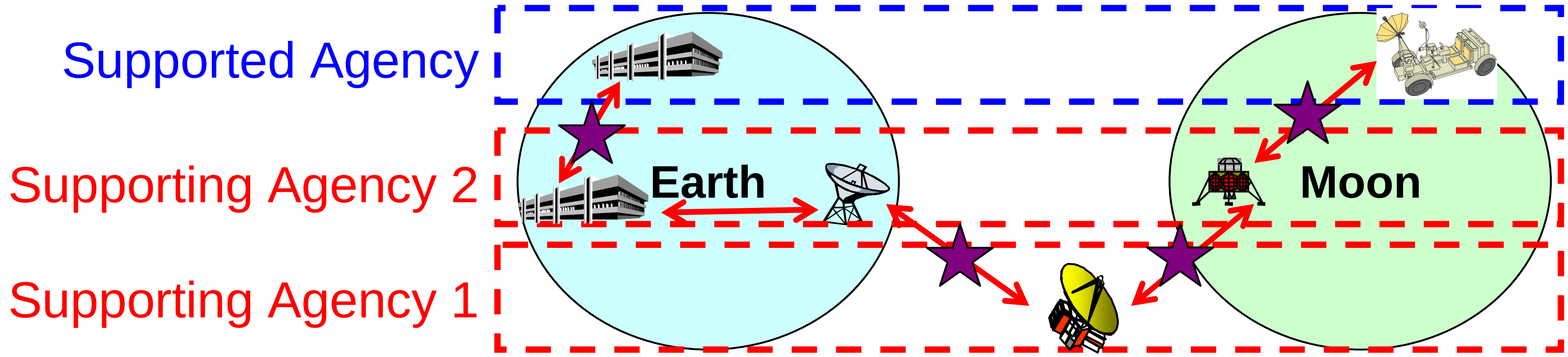


Infrastructure Enhancements

- Standard service management functions for all component networks:
  - Service planning & request scheduling
  - Service accountability reporting
- Service management interface will comply with CCSDS standard (under development)
- Common network management functions for all component networks:
  - Network scheduling & asset configuration control
  - Network asset monitoring during operations
- SCaN Services Catalog defines standard services

Increasing Interoperability

Ground, Orbiter, & Surface Interoperability



- **Standard services will include:**
  - **Relaying services (routed and store-and-forward deliveries) for Files, Space Packets, Commands & Telemetry**
  - **Positioning services (ranging and orbit determination)**
  - **Timing services (clock distribution and synchronization)**
  - **Management services (service requests & reporting, data accountability, configuration management)**

- **Standard protocols form the basis of an open, internationally interoperable architecture:**
  - **Surface links: IEEE 802.x**
  - **Surface-to-orbiter links: CCSDS Proximity-1 or its enhanced version**
  - **Orbiter-to-earth and direct-to-earth links: CCSDS TC/TM Space Data Link with Space Packet**
  - **Ground links: CCSDS SLE on top of TCP/IP**
  - **End-to-end: CCSDS CFDP or DTN**

Lunar Vicinity Frequency Plan

Summary Report of 3rd Meeting of SFCG, Lunar/Martian Spectrum Coordination Group, 3 April 2008

Band	Forward	Agency	Return	Agency	Notes
Operational direct from/to Earth					
S-Band	2025-2110 MHz	All	2200-2290 MHz[5]	All	
X-band	7190-7235 MHz	Roskosmos ESA ISRO JAXA CNSA	8450-8500[1] MHz	Roskosmos ESA ISRO JAXA CNSA	
Ka-Band	22.55-23.55[2] GHz	NASA DLR[a]	25.5-27 GHz[3]	NASA DLR JAXA[b]	[a] Narrowband Ranging [b]Downlink only beyond 2018
Lunar Relay Trunk Line					
Ka-Band	40-40.5 GHz	NASA	37-38 GHz[7]	NASA	
Lunar relay to/from Orbiter or Surface; Orbiter to/from Surface; Orbiter to Orbiter					
UHF	435-450 MHz[4]	JAXA ISRO	390-405 MHz[4]	JAXA ISRO	
S-Band	2025-2110 MHz	NASA JAXA	2200-2290 MHz[5]	NASA JAXA	
Ka-Band	22.55-23.55 MHz	NASA	25.5-27 GHz[3]	NASA	
Surface to Surface [6]					
UHF	410 - 420 MHz	NASA	410 - 420 MHz	NASA	Under study
IEEE 802	868 - 915 MHz, 2.4 GHz	NASA	868 - 915 MHz, 2.4 GHz	NASA	Under study
Lunar Relay to Lunar relay Cross link					
Ka-Band	37-38[7] GHz	NASA	40-40.5[7] GHz	NASA	Reverse Band
Ka-Band	22.55-23.55 GHz	DLR	25.25-27.5 GHz	DLR	Under study for sub-satellite ISL
Ku-Band	13.75-14 GHz	DLR	14.5-15.35 GHz	DLR	Under study for sub-satellite ISL

Used by many. Agreed. Interoperability possible.
Used by many. Agreed. Interoperability potential. Discussion on sharing the band.
Used by one agency (no interoperability discussion needed at this stage). Agreed.
Still to be discussed.

Lunar Vicinity Frequency Plan

Summary Report of 3rd Meeting of SFCG, Lunar/Martian Spectrum Coordination Group, 3 April 2008

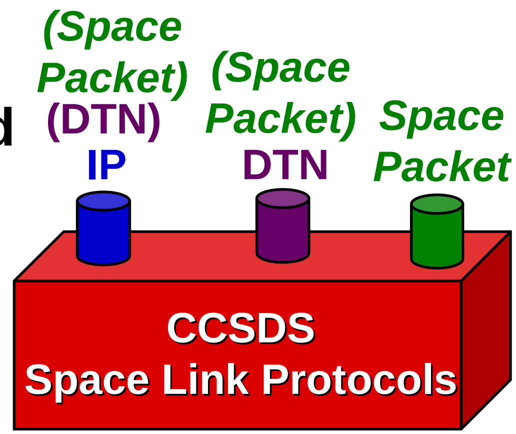
- **Notes**
  1. **SFCG Recommendation 5-1R5 limits individual mission bandwidths to 10 MHz.**
  2. **A new allocation for at least 500 MHz SRS uplink spectrum is required.**
  3. **Coordination is required among all different users of the band: SRS for lunar missions, SRS for non-lunar missions, EESS. The specific issue of manned mission protection criteria will be discussed at SFCG.**
  4. **The ability to share these lunar surface bands with Earth-based radars needs to be confirmed.**
  5. **Suitable for interoperability, but the band needs to be used wisely, since it is widely used for nearly all the space missions including low earth orbit missions. Application of the SFCG Resolution 24-1 is necessary (6 MHz bandwidth limit and no emission when it is not necessary to transmit).**
  6. **Band selection under study.**
  7. **Utilization of these bands are subject to SFCG Recommendation 14-2R5. Also, these band are not allocated for Inter-satellite Service crosslinks.**

Technology Improvements

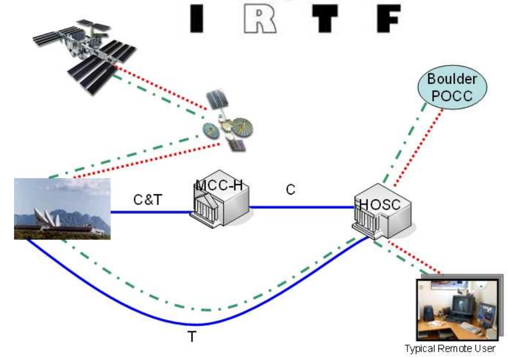
- **Communications**
  - **Transition from X- to Ka-band for greater bandwidth**
  - **Replace 70m subnet with arrayed antennas for robustness & scalability**
  - **Optical communication for vastly greater bandwidth**
  - **SW Defined Radios for post-launch reprogrammability**
- **Navigation**
  - **Autonomous landing & hazard avoidance technology for precision EDL (ESMD's ALHAT Project)**
  - **Lunar satellite & beacon-based surface navigation for high precision landing & roving**
- **Network Integration & Interoperability**
  - **Standardized services & service management across all networks**
  - **Enhanced interoperability for expanding presence across the solar system**
  - **Disruption Tolerant Networking (DTN) combines Internet Protocol routing with Store & Forward capability for assured transmission in spite of losing connection**

Disruption Tolerant Networking (DTN)

- **Purpose: To provide network services in the face of disruption and massive differences in delay and bandwidth; and to reduce demands on network resources by integrating storage into the network**
- **Produce an internationally standardized and off-the-shelf family of interoperable DTN protocols that is ready for space mission use:**
  - **A "Space DTN" suite of standards that is interoperable with the open community DTN developments in the Internet Research Task Force (IRTF), including:**
    - **a set of associated DTN network management protocols**
    - **a set of Reference Software for interoperability testing**
    - **code to assist with flight project implementations**
  - **Demonstrated in a flight qualified environment**
- **Advance the DTN technology readiness to TRL 8/9**
- **Deep Impact Network (DINET), Nov 2008: Successfully demonstrated DTN on EPOXI while 20M miles from Earth treating it as a Mars data-relay orbiter**



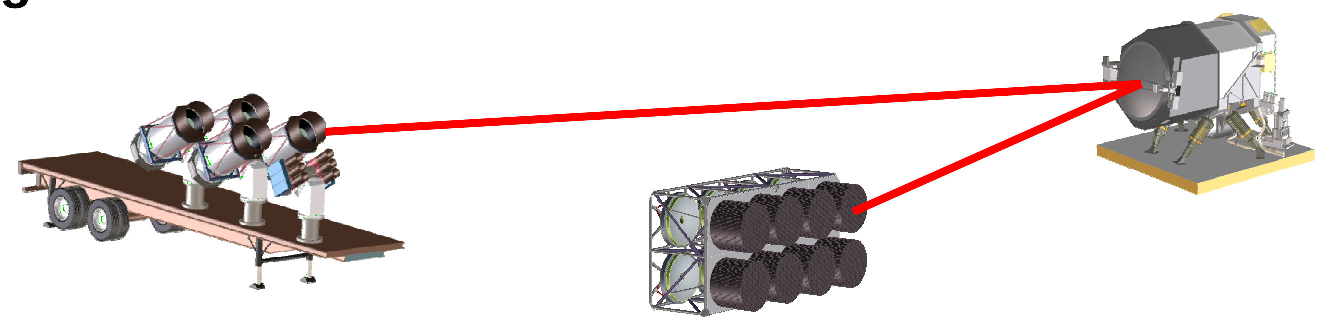
Delay Tolerant Networking Research Group



Optical Communications Roadmap

- **Goals established by Administrator Griffin:**
  - **Operational lunar optical communications by 2018**
  - **Operational Mars optical communications by 2023-25**
- **Accelerated technology development program being formulated addressing ground & space-based terminal options**
  - **Flight demo on LADEE in 2011**

Deep space user terminal (50 cm, 10 W)
Data rate from Mars: 100+ Mbps



Mobile Optical Ground Terminal Demo

Deep Space Optical Relay 3m Telescope using array of 1m devices

Software Defined Radios (SDR)

- SDRs provide remote reprogrammability for:
  - Reconfiguration of communication and navigation functions according to mission phase
  - Post-launch software upgrades
  - Use of common hardware platforms for multiple radios over a variety of missions
- Agency SDR Infrastructure
  1. Space Telecommunications Radio System (STRS) SDR Standard Architecture Specification (STRS Release 1.1, May 07)
  2. HW and SW Component Library with broad early acceptance criteria, becoming more stringent as the infrastructure matures
     - Projects select and procure library components as needed
  3. Design Reference Implementation Specifications using standard-compliant library components
  4. Tools and Testbeds for SDR design, development and validation
  5. Demonstrations of STRS-compliant units on the ground and in space
     - SCaN CoNNecT Orbiting Testbed to fly in 2011 on ISS

Commercial Lunar C&N Study

- **Background**
  - **U.S. Space Exploration Policy & NASA Authorization Act of 2005 direction is to "promote international and commercial participation in exploration"**
  - **Exploration Systems Mission Directorate studies to date have treated Communication & Navigation (C&N) as if entirely provided by NASA**
  - **Combination of Science & Exploration plans offers a natural evolutionary path for Communications and Navigation capabilities**
    - **2010's: Initial support for increasing number of lower rate science stations scattered over near & far side**
    - **2020's: Expanded support for human missions with establishment of Lunar Outpost and sortie missions anywhere on Moon**
  - **Both programs plan to incorporate major contributions from international partners**
  - **Exploration plans to (& ILN may) benefit from commercial partners**
- **Study conducted in collaboration between Mission Directorates (Exploration, Science, & Space Operations) and major programs (Commercial Orbital Transportation Systems – COTS; Constellation; Planetary Science – ILN; and SCaN)**

NASA Implementation Philosophy

- The US will build the transportation infrastructure and initial communication & navigation and initial EVA
- Open Architecture: NASA will welcome external development of lunar surface infrastructure

- The US will perform early demonstrations to encourage subsequent development
- External parallel development of NASA developed capabilities will be welcomed

Source: Exploration Strategy and Architecture, *Shana Dale*, 2nd Space Exploration Conference , December 4, 2006

Open Architecture: Infrastructure Open for Potential External Cooperation

- **Lander and ascent vehicle**
- **EVA system**
  - CEV and Initial Surface capability
  - Long duration surface suit
- **Power**
  - Basic power
  - Augmented
- **Habitation**
- **Mobility**
  - Basic rover
  - Pressurized rover
  - Other; mules, regolith moving, module unloading
- **Navigation and Communication**
  - Basic mission support
  - Augmented
  - High bandwidth
- **ISRU**
  - Characterization
  - Demos
  - Production
- **Robotic Missions**
  - LRO- Remote sensing and map development
  - Basic environmental data
  - Flight system validation (Descent and landing)
  - Lander
  - Small sats
  - Rovers
  - Instrumentation
  - Materials identification and characterization for ISRU
  - ISRU demonstration
  - ISRU Production
  - Parallel missions
- **Logistics Resupply**
- **Specific Capabilities**
  - Drills, scoops, sample handling, arms
  - Logistics rover
  - Instrumentation
  - Components
  - Sample return

**** US/NASA Developed hardware**

Source: Exploration Strategy and Architecture, *Shana Dale*, 2nd Space Exploration Conference, December 4, 2006

Implementing the Vision

Commercial Lunar C&N Study Tasks

- Updated LAT2 traffic models based on latest CxAT architecture
- Study team assessed "essential C&N" (a.k.a., initial or basic)
  - What does NASA commit to providing & what is the commercial opportunity?
- Issued RFI for Commercial Lunar C&N in August
  - Encouraged participation by foreign & non-prime aerospace players
- Held two industry workshops on Commercial Lunar C&N
  - September – over 50 attendees reviewed proposed approach
  - November – gained industry consensus on recommendations & approach for work in 2009
- Contracted with Futron to assess lunar C&N market
- Analyzing options for commercial strategy based on above
- Final report in January

NASA Authorization Act of 2008

- ***SEC. 404. LUNAR OUTPOST.***
- *(a) ESTABLISHMENT.—As NASA works toward the establishment of a lunar outpost, NASA shall make no plans that would require a lunar outpost to be occupied to maintain its viability. Any such outpost shall be operable as a human-tended facility capable of remote or autonomous operation for extended periods.*
- *(b) DESIGNATION.—The United States portion of the first human-tended outpost established on the surface of the Moon shall be designated the ''Neil A. Armstrong Lunar Outpost''.*
- *(c) SENSE OF CONGRESS.—**<u>It is the sense of Congress that NASA should make use of commercial services to the maximum extent practicable in support of its lunar outpost activities.</u>***

NASA Authorization Act of 2008

- ***SEC. 408. PARTICIPATORY EXPLORATION.***
- *(a) IN GENERAL.—The Administrator shall develop a technology plan to enable dissemination of information to the public to allow the public to experience missions to the Moon, Mars, or other bodies within our solar system by leveraging advanced exploration technologies. The plan shall identify opportunities to leverage technologies in NASA's Constellation systems that* ***deliver a rich, multimedia experience to the public****, and that* ***facilitate participation by the public, the private sector, nongovernmental organizations, and international partners****.* ***Technologies for collecting high-definition video, 3-dimensional images, and scientific data, along with the means to rapidly deliver this content through extended high bandwidth communications networks, shall be considered as part of this plan.*** *It shall include a* ***review of high bandwidth radio and laser communications, high-definition video, stereo imagery, 3-dimensional scene cameras, and Internet routers in space, from orbit, and on the lunar surface.*** *The plan shall also consider secondary cargo capability for technology validation and science mission opportunities. In addition, the* ***plan shall identify opportunities to develop and demonstrate these technologies*** *on the International Space Station and robotic missions to the Moon, Mars, and other solar system bodies. As part of the technology plan, the Administrator shall examine the feasibility of having NASA* ***enter into contracts and other agreements with appropriate public, private sector, and international partners to broadcast electronically, including via the Internet, images and multimedia records delivered from its missions in space to the public****, and shall identify issues associated with such contracts and other agreements.*

NASA Authorization Act of 2008

- ***TITLE IX—COMMERCIAL INITIATIVES***
- ***SEC. 901. SENSE OF CONGRESS.***
- *It is the sense of Congress that a healthy and robust commercial sector can make significant contributions to the successful conduct of NASA's space exploration program. While some activities are inherently governmental in nature, there are many other activities, such as routine supply of water, fuel, and other consumables to low Earth orbit or to destinations beyond low Earth orbit, and* <u>***provision of power or communications services to lunar outposts, that potentially could be carried out effectively and efficiently by the commercial sector at some point in the future. Congress encourages NASA to look for such service opportunities and, to the maximum extent practicable, make use of the commercial sector to provide those services.***</u> *It is further the sense of Congress that United States entrepreneurial space companies have the potential to develop and deliver innovative technology solutions at affordable costs. NASA is encouraged to use United States entrepreneurial space companies to conduct appropriate research and development activities. NASA is further encouraged to seek ways to ensure that firms that rely on fixed-price proposals are not disadvantaged when NASA seeks to procure technology development.*

Preliminary RFI Results

- 23 responses received – 19 domestic, 4 foreign
- Responders can be divided into 1st, 2nd, 3rd tier providers & others
  - "Full service" providers: 5 (1 foreign)
  - Segment providers: Space- 5 (1 foreign); Ground- 1; Surface- 3 (1 foreign)
  - Subsystem/Component providers: 9 (2 foreign)
    - "NewSpace" start-ups: 1
    - University: 1
  - (2 Non-providers support a pro-commercial approach)
  - Did not get response from major commercial service operators (e.g., Intelsat, SES, Eutelsat, JSAT, Loral, Telesat)
- Private sector well positioned to provide Commercial C&N services
- Market from space agencies & other users has to be aggregated & long term commitment provided to close business case
  - Nav market limited – may be an "essential government" function
- No consensus on recommended approach but included:
  - COTS-like NASA investment, INTELSAT-like government sponsored corporation, Public/Private Partnership, fully private
  - Required NASA investment varies from 0-100%

Preliminary RFI Results

- **Segment providers prefer to see acquisition partitioned to avoid competing with Full Service providers**
- **NASA (DSN & NEN) seen as competition**
- **Agree with Ka-band as primary spectrum for trunk & S-band for proximity links**
  - **Spectrum allocations to government-only bands are an issue**
  - **One proposal to provide optical capability**
- **Agree with incremental evolution to increase capability**
- **Open, standards-based architecture essential or assumed**
- **Suggested forming an industry advisory group**

Summary of Strategy Options

- **Option 0 – NASA Owned & Operated**
  - The non-commercial option
- **Option 1 – Count on Commercial**
  - NASA relies on commercial providers to invest & implement their plans for C&N to support Human Exploration
- **Option 2 – NASA Develops & Privatizes**
  - NASA develops the service with commercial firms, then privatizes it to recoup costs (Near Earth Network model)
- **Option 3–NASA develops HDR, buys Commercial L-MDR**
  - Industry develops the Low-Medium Data Rate, noncritical C&N capabilities; NASA buys the services on a fixed price basis
  - NASA develops High Data Rate (e.g., optical) capability & transitions technology to industry

Summary of Strategy Options

- **Option 4 –Commercial-leveraged Model (COTS model)**
  - **NASA invests via Space Act Agreement (SAA) but industry owns; NASA buys fixed price services**
  - **C&N industry develops the C&N capabilities and services**
- **Option 5 – Create Public/Private Partnership (Intelsat model)**
  - **NASA, other International Space Agency's (ISA), & industry combine lunar C&N "needs" to invest in a publicly chartered, privately owned entity (Public/Private Partnership) to provide C&N services for all lunar users**

Top 2 Options Comparison

Option 4: Commercial-leveraged Model	Option 5: Public/Private Partnership
• NASA-demand only	• Integrated, collaborative demand • NASA + space faring agencies
• NASA shares costs alone with industry but has control through SAA	• NASA gives up some control • Shared investment with international and commercial partners
• NASA focuses only on its spectrum & BW demand	• Better chance of forcing common standards/spectrum
• Prompt on-ramping of C&N services	• Improves collaboration with international partners
• Higher investment cost and $/kbps for service (compared to Option 5)	• Lower cost for development, ops, investment • Higher guarantee of reward to balance commercial risk in industry

3 Phases of Commercial Lunar C&N Strategy

- **S-1 (2010-2013)**
  - **Ops: Early Missions = DTE Communication**
    - **Likely commercial & prize flights, e.g., Google Lunar X-Prize**
  - **Testing & Development**
    - **Subsystems DDT&E**
    - **Test/Dev S-2/Demos**
    - **Early Commercial Backbone**
    - **Key is synergy between NASA, Commercial and DOD test programs**
- **S-2 (2013-2018)**
  - **Ops: ILN + International Science missions + other NASA Lunar Quest missions**
    - **Products and User by Commercial C&N Network Backbone**
    - **No NASA Network Backbone**
- **S-3 (2018-2020+)**
  - **Ops: Human Exploration (Sortie & Outpost) missions + ILN + International Science missions + other NASA Lunar Quest missions**
    - **S2 content + Outpost science/user data**
    - **Manned ops for outpost/Altair (assured comm) by backbone network**

Conclusions

- Updated traffic models results in no basic change from LAT2 trunk link results: 100 Mbps forward / 250 Mbps return
- "Essential C&N" was redefined in terms of assessing the NASA/Partner split in data transport allocation
  – Result: Best option is to transport all data via commercial provider while NASA provides a redundant path to mitigate risk
- Lunar C&N could be obtained via a commercial approach
  – Industry willing with appropriate NASA commitment
  – Viable system approaches:
    - Single E2E turnkey system integrator / operator
    - Partition into Ground/Space/Surface segments
  – Viable programmatic approaches (in order of decreasing score)
    1. Public/Private Partnership (PPP) (INTELSAT) approach is flexible & good for global investment
    2. Commercial-leveraged (COTS) approach to reduce commercial entry barrier & assure satisfaction of NASA needs
    3. NASA develops & privatizes to recoup cost

Study Recommendation

- **Develop a plan to form a government sponsored Public/Private Partnership (PPP) with investment from US & international agencies + industry as a powerful way to initiate broad, permanent commercial development**
  - **Provides open-ended method for future investment**
  - **Mitigates risks via long term commitments by government agencies combined with industry investment**
  - **Provides greatest potential to build a business case that sells**
  - **Enables NASA to invest initially & control development yet recover investment by selling to industry later**
    - **Exit plan recovers funds for going to Mars & leaves legacy commercial market**
  - **Popular approach in Europe could encourage ESA & European member agencies' participation**
  - **Initial line of business could be C&N, then expand to power, ISRU, fuel depots, etc.**

Agenda

- Context for Change
- Lunar Network in the context of Exploration Systems
  - Communications
  - Navigation
  - Networking
- Lunar Network in the context of Science's International Lunar Network
- Lunar Network in the context of NASA's Integrated Network Architecture
  - Communications, Navigation & Networking Services
  - Integrated Service Portal
  - Commercial & International Partnering
- Conclusion
- SE Challenges

Conclusions (1)

- SCaN infrastructure is undergoing extensive modernization to continue to provide highly reliable service for decades to come meeting challenges stay ahead of mission demands
- Arrayed antennas, RF enhancements, and new optical relays are being developed to continue to provide orders of magnitude improvement in data rates & robustness to meet the needs of increasingly complex solar system missions
- Standardization of services will enable nearly seamless interoperation across NASA's networks, more standardized & cheaper mission subsystems
- The Integrated Service Portal will standardize planning & execution across networks enabling mission programs & Centers to further lower costs

Conclusions (2)

- International interoperability will enhance mission flexibility & provide increasing opportunities for collaboration on major initiatives such as Mars Sample Return
- Solar System Internetwork will be defined over the next 3 years based on evolving to an interplanetary routed data transport architecture using Internet Protocol (IP), Disruption Tolerant Networking (DTN), & Space Packet
- International spectrum coordination is evolving from compatibility (non-interference) to interoperability in concert with standard protocols

Conclusions (3)

- **In response to major new requirements from Exploration Systems & Science Mission Directorates, SCaN will establish a Lunar Network in the next decade**
  - **Still in pre-formulation studies**
  - **Commercial approach through an international Public/Private Partnership is the leading contender to foster economic growth & coordinate international capabilities & needs**
  - **Other approaches will continue to be studied**
  - ***Mars Forward*: Lunar architecture is being designed to extend to future Mars Network architecture**

Agenda

- Context for Change
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Problems due to BIG Systems

- **SoS → PoP**
  - **So-called *Systems of Systems* challenges are really mostly *Program of Programs* challenges**
  - **SE techniques, e.g., trade studies & decomposition, run into barriers due to program (& other organization) boundaries**
  - **Some organizational boundaries are easier to negotiate than others, e.g., intra-Program within NASA vice foreign space agency**
- **Time phased development creates inefficiencies**
  - **CxP is developing systems in 4 phases: 1) Ares I/Orion to ISS; 2) Ares V/Altair to Moon; 3) Lunar Surface Systems; 4) Mars**
  - **Orion needs to be lunar capable but lunar architecture & requirements will not be defined in time to meet Orion schedule**

Differences between Programs & Projects

- NPR 7120.5D asserts that Programs are started (Pre-Formulation & Formulation) before establishing Projects, then have an open-ended Implementation phase
  - Most Programs do not plan for Disposal phase (ISS)
  - Infrastructure programs (SCaN) may last as long as Agency
- Most Projects have well defined life cycle with clear decommissioning
  - Infrastructure projects may last as long as their Program or may be replaced by new technology performing same function
- Loosely coupled Programs (e.g., MEP) conduct serial missions with continuity in Science and Comm
- Tightly coupled Programs usually do all major SE up front
  - Exception is CxP with 4 phases
  - Each phase drives changes in SCaN systems
- SCaN evolving from loosely to tightly coupled forcing key decisions to Agency level

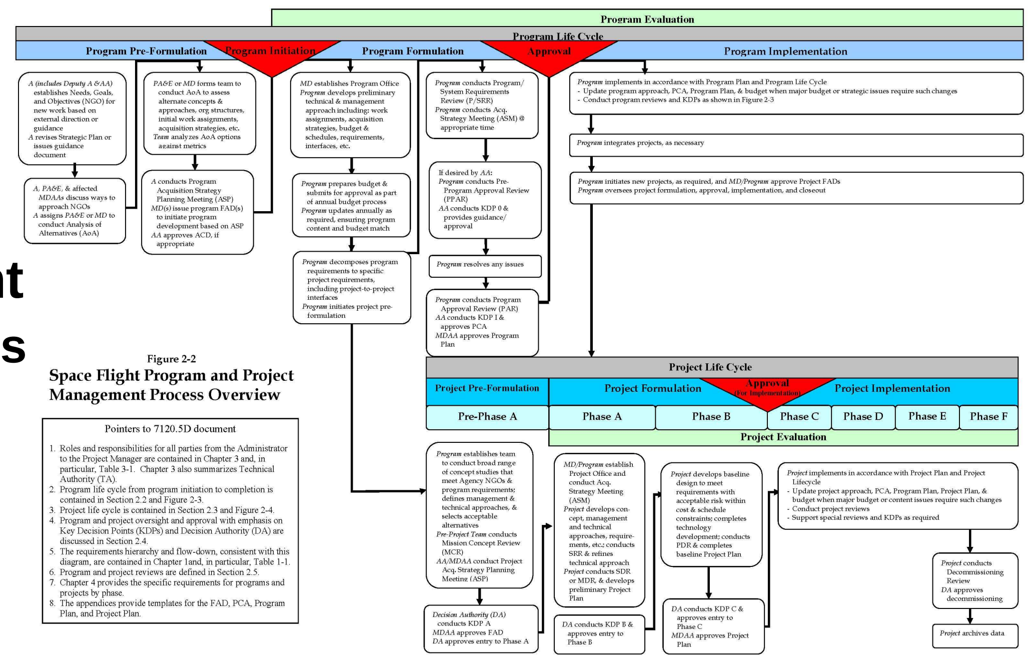

Figure 2-2
Space Flight Program and Project Management Process Overview

Unique Aspects of SCaN

- **SCaN is both a Directorate Office & a Program Office**
  - SCaN is the only NASA Program managed at HQ
  - Responsible for Agency Spectrum Management, Space Comm standards & technology development, Memos of Agreement with other US Government & foreign space agencies
  - Struggling with program-level management approach
- **SCaN Program formed with three networks already operational**
  - Typical new Program starts at the beginning of the Program life cycle, able to do top level SE&I before starting Projects
  - SCaN occupied with daily management of ops projects
  - SCaN challenge is to transform networks with decades of independent operations experience into one unified Network of Networks
- **SCaN is the only infrastructure program with space assets**
  - How do NASA policies NPR 7120.5D & 7123.1A apply?